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THESIS

AN EVALUATION OF THE UNITED STATES ARMY SESAME
AND SWEDISH OPUS VII PROVISIONING MODELS

by

Carl Frank Menyhert

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Thesis Advisor: M. Kline

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The SESAME and OPUS VII models and their problem-solving methods

Block 20 Cont.

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An Evaluation of the United States Army SESAME and Swedish OPUS VII Spares Provisioning Models

by

Carl F. Menyhert
Captain, United States Army
B.S., United States Military Academy, 1976

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Author: Carl F. Menyhert

Approved by: Melvin B. Kline
Thesis Advisor

Second Reader

Chairman, Department of Operations Research

K.T. Marshall
Dean of Information and Policy Sciences

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The SESAME and OPUS VII models and their problem-solving methods are described. Mathematical overviews of each model are examined. Differences between the models, their advantages and limitations are discussed. Each model is evaluated in terms of input parameters, required structure of systems, types of outputs, and model shortcomings.

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I. INTRODUCTION

A. BACKGROUND

Recent studies show that the ability of a modern army to fight has placed additional burdens upon the logistics system that support it [Ref. 1]. Success in modern combat requires operationally and technically superior combat ready material, men, and support systems. With the advent of high technology weapon systems, the shortcomings in the present logistics system have warranted the revision of support concepts and structures.

Rear Admiral Henry Eccles (U.S.Navy-Ret) has pointed out that, although great strides have been made in the field of logistics management, some of our most important unsolved problems are logistical in nature [Ref. 2]. The deficiencies and contradictions within our logistics systems are often caused by our lack of or imperfect knowledge of the art and science of logistics. The importance of logistics in the nature and conduct of modern warfare must not be disregarded.

Logistics managers are required to develop new concepts to meet the new demands and challenges that the modernized Army has created. In addition to budgetary constraints, Prof. W.H. Marlow states that the logistician must deal with the new readiness and responsiveness postures that have been outlined in DoD Directive 5000.39 [Ref. 3]. Maj. Gen. Homer D. Smith (U.S. Army) points out that one of the major areas facing logisticians and research engineers is the coupling of system reliability to the cost of manpower and repair

parts [Ref. 4]. Furthermore, the crisis in the Middle East in October 1973 has shown that the effectiveness of our tactical forces are more dependent than ever upon their ability to deploy rapidly in full readiness for combat. It is, thus, evident that our ability to sustain prolonged combat depends upon our logistics effectiveness. A Joint Logistics Review Board chaired by General Frank S. Benson Jr. (U.S. Army) produced findings concerning support during the Arab-Israeli War. These findings showed the need for forward support during the early days of the conflict [Ref. 1]. The Board accurately identified the spare parts layering problem but did not mention the consequences of shortages. The JLRB defined the layering problem as how many spare parts to stock at specified maintenance echelons.

Effective logistic support is essential to maintain a high degree of military readiness. Efforts have been initiated recently to correct the deficiencies within existing logistic structures. DoD has established guidance in DoD Directive 5000.39 [Ref. 5] and DoD Instruction 5000.2 [Ref. 6] which directs the acquisiton process towards the goals of readiness and availability [Ref. 7]. According to Assistant Secretary of Defense James N. Juliana, efforts are being made to relate stockage decisions to weapon systems readiness [Ref. 8]. The key phrases within these new DoD guidance documents are "quantitatively related" and "system readiness". A key concept of this new guidance is that of operational availability.

Availability is now being considered the key operational characteristic for measuring system effectiveness [Ref. 9]. The increase in readiness through increased availability has become a major concern of recent logistics efforts. One way to increase equipment availability is to insure that the correct amounts of the required spare parts are on hand at

the proper place and time and to the proper depth in the system hierarchy [Ref. 10].

Through the use of computer models, potential solutions to logistics problems can be quickly evaluated based upon defined measures of effectiveness such as availability. There exists a need to relate these measures of effectiveness to specific decision-making processes in supply and maintenance management.

B. OBJECTIVE

The objective of this thesis is to provide information about logistics provisioning models through the evaluation of two specific models. It is part of a larger study being conducted by the Department of Defense to analyze and evaluate several level-of-repair and provisioning models. The measure selected is operational availability (A_O) which is the currently specified DoD measure of effectiveness [Ref. 11]. Operational availability is a measure of the field reliability, maintainability and supportability of systems and equipments and the impact of these parameters upon mission fulfillment.

C. TYPES OF EQUIPMENT

Different types of systems and equipment used within the Armed Forces cannot be treated in the same manner. The technical characteristics of electronic equipment cannot be compared to the technical characteristics of a wheeled vehicle. There are several simplifications when dealing with electronic equipment. Foremost is the fact that times between failures are often accurately modelled with the exponential distribution. This results in much better mathematical tractability with failures occurring in accordance with a Poisson process. Both computer models

evaluated in this thesis define availability in terms of exponentially distributed failures. Due to the nature of electronic equipment, maintainability is mostly concerned with corrective maintenance. The area of preventive maintenance is limited to such things as tests, calibrations and monitoring during normal operation. Studies have been conducted that indicate that corrective maintenance time follows a lognormal distribution [Ref. 12]. Mathematical evaluation of failures, repair time, and supply response times leads to an evaluation of the expected system effectiveness (operational availability).

D. APPROACH

This research is geared to the investigation of the numerical outputs of two logistic models with the emphasis upon analyzing differences caused by different problem solving algorithms and input data. The intent of such investigations is the determination of computational models that are simpler to use and evaluate, thus enhancing the applicability of the models [Ref. 13].

The structure and problem solving algorithms of each model are examined in this thesis. Mathematical overviews are presented which show how solutions are determined. Each model is evaluated in terms of input parameters, required structure of systems, types of outputs, and model shortcomings.

A sample problem is run for both models and the outputs are compared. Differences are evaluated with respect to isolating the input parameters that caused the change and the sensitivity of each model to changes in inputs.

The analysis consists of the use of computational techniques leading to the ranking of alternatives based upon:

--operational availability at a fixed cost level;

--minimum cost to achieve a specified operational availability.

E. THESIS STRUCTURE

The structure of this thesis and the relationships between chapters are illustrated in Figure 1-1.

Chapter II discusses the functions of the U.S. Army SESAME model. It describes the structure and purpose of the SESAME model, and the general uses of SESAME.

Chapter III discusses the functions of the Swedish OPUS VII model. It describes the structure and purpose of the OPUS VII model, and the general uses of OPUS VII .

In Chapter IV, sample input structures used to compare the two models are developed. The rationale and an evaluation of possible causes for error are discussed.

In Chapter V the results of these models are compared and evaluated, including relative strengths and weaknesses.

Chapter VI provides conclusions and recommendations resulting from the analysis.

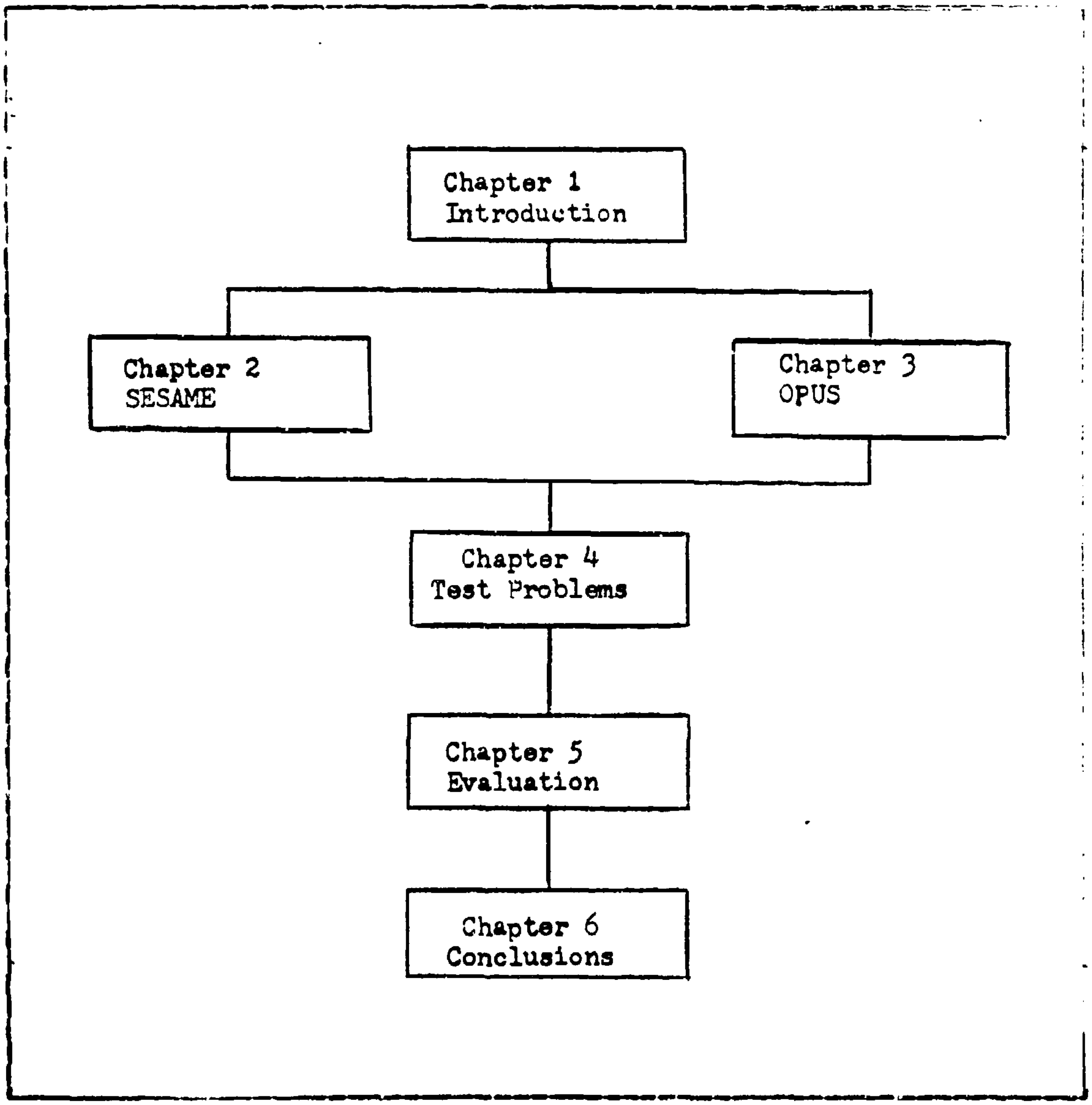


Figure 1.1 Thesis Structure.

II. THE SESAME MODEL

A. BACKGROUND

The concept of "sparing to availability" has become a policy of the Department of Defense. The idea of "sparing to availability" means that it is now necessary to consider the effect of each item upon the system's ability to complete its mission. One important requirement in the sparing to availability concept is that the specified level of availability must be achieved at a minimum cost.

SESAME stands for Selected Stockage for Availability Multi-Echelon Method. It is used by the United States Army for determining provisioning levels and war reserve requirements [Ref. 14]. SESAME was developed by the U.S. Army Inventory Research Office as a tool to support weapon systems and end items which could not be supported by demand-supported criteria. As a spares optimization model, SESAME computes the least cost mix of spares that will provide a specified level of system availabilty (Figure 2.1). Figure 2.1 represents the optimal stockage using the SESAME model. The endpoints represent boundaries created by cost limits and the Standard Initial Provisioning (SIP) requirement. It is one of four spares optimization models that have been used by the Army as initial provisioning models [Ref. 15].

SESAME is an analytic computer model that can handle multi-item, multi-system, multi-echelon inputs. It determines which items to stock, and where and in what quantities to stock them. SESAME determines these amounts while optimizing operational availability for a given cost.

The model was developed by the United States Army Development and Readiness Command (DARCOM) Provisioning

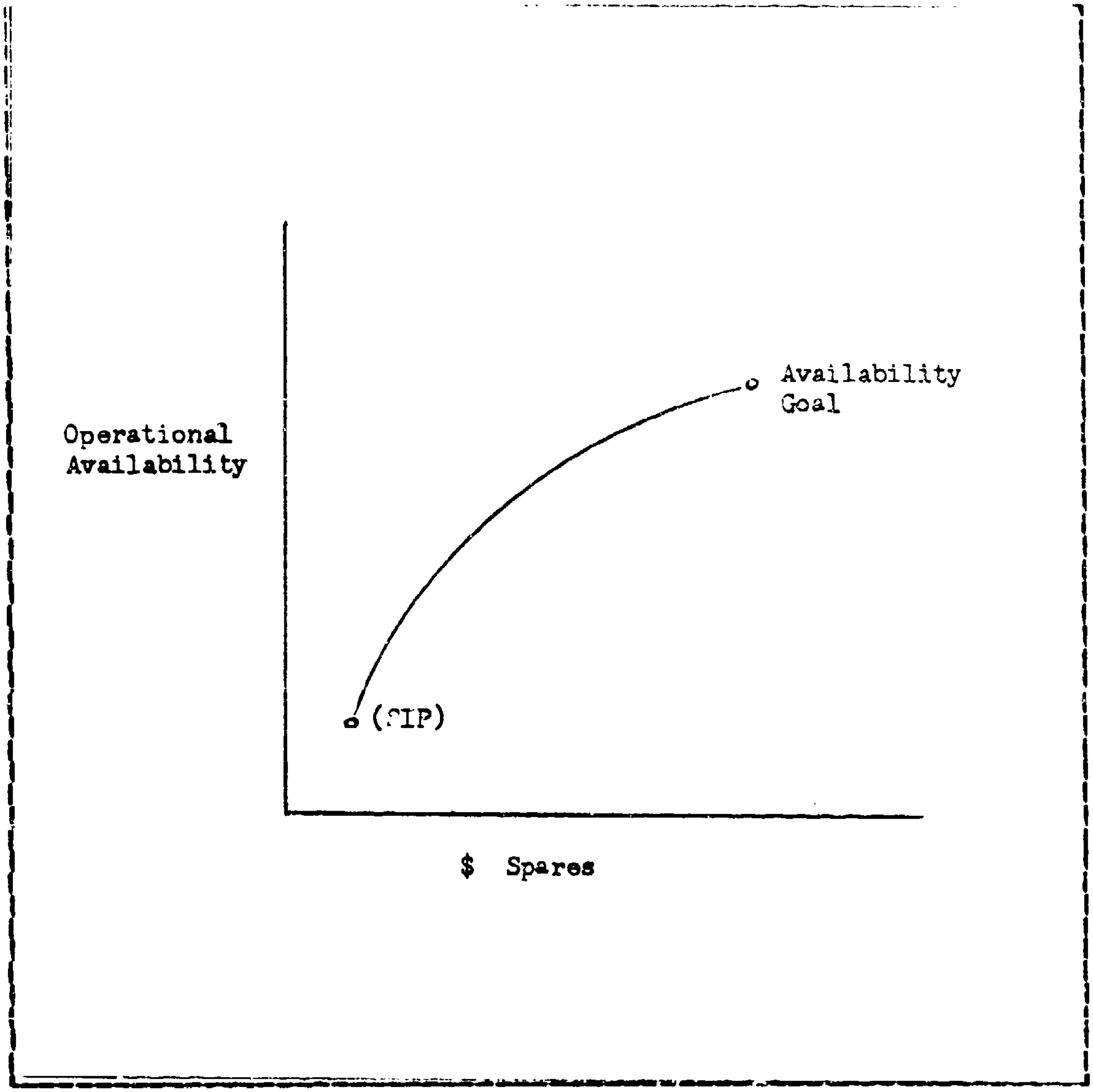


Figure 2.1 Spares Stockage versus Availability.

Technical Workshop. The Army Inventory Research Office (IRO) had previously developed a model which was capable of calculating the range and quantity of spares and repair

parts necessary to support a new item/weapon system, the Standard Initial Provisioning (SIP) model. SESAME is an outgrowth of these earlier efforts.

B. APPLICATIONS

There are two major usages of the SESAME Model, (1) budget preparation (both peacetime and wartime), and (2) determination of essential repair parts stockage list (ERPSL) items (Figure 2.2).

In the budgeting mode, the program computes a projected total cost which serves as an estimate for the funding requirements for new systems that are to be deployed. Since the systems are usually still in early stages of development, in this mode SESAME requires only aggregated dollar figures as input. This input uses data gathered from whatever assemblies are available at the time. These items are ranked by means of the parameter Mean-Time-Between-Failure per Unit Cost, and the provisioning cost for each is calculated by SESAME. The ERPSL application determines availability and cost based upon detailed data about the components and parts.

SESAME may be used for both Peacetime and Wartime applications. Both share the same algorithms. The Peacetime requirements are used to represent expected initial deployment and peacetime usage rates. The Wartime requirements are used to examine different scenarios, which can represent differing levels of combat intensity, combat loss and delays due to combat. At present, SESAME cannot handle a surge in supply requests.

C. ASSUMPTIONS

The following assumptions are made by the SESAME model:

1) A system of up to three echelons exists; each unit

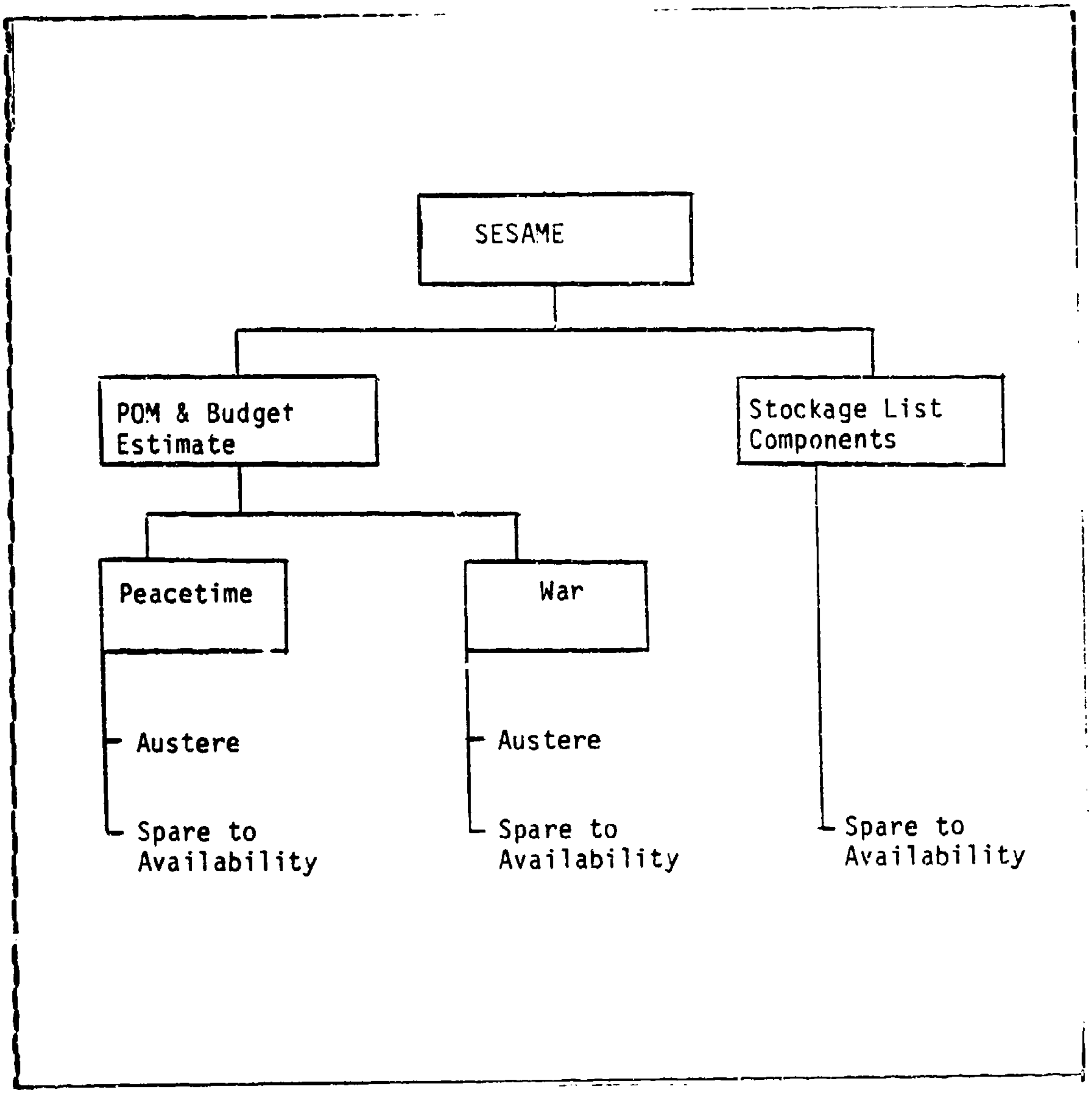


Figure 2.2 SESAME Usage Modes.

may be supported by only a higher echelon.

2) SESAME is run on only one weapon system at a time.

3) Upon failure, a replacement is automatically ordered and the bad part is either discarded or sent to a repair facility.
4) Line Replaceable Units (LRUs) and Shop Replaceable Units (SRUs) are identified.
5) Failures are independent, occur at random times, and follow an exponential distribution.
6) SESAME does not recognize constraints such as states of limited operational capability.
7) In order to deal with operational spares (rotatable items that can be put into use while a system is under repair), the failed item must be dealt with as an LRU, or SESAME must be supplemented with additional programs [Ref. 16].

D. PERFORMANCE USING OPERATIONAL AVAILABILITY (A_0)

SESAME uses operational availability as a performance measure. Operational availability measures the ability of an end item/system to enter its mission and is defined as the percentage of time that a system is mission capable. Operational availability is a requirement determined by the user.

Operational Availability is defined by Army Regulation 702-3 as "the degree to which an item is either operating or is capable of operating at any random point in time" [Ref. 17]. This is equal to the amount of equipment uptime divided by the amount of equipment downtime plus uptime. In the case of this equation uptime is defined as either operable or in a standby state.

$$A_O = \frac{\text{Uptime}}{\text{Uptime} + \text{Downtime}} \qquad (2\text{-}1)$$

SESAME converts this equation to

$$A_o = \frac{\text{Average Uptime per cycle}}{\text{Average length of a cycle}} \qquad (2\text{-}2)$$

where a cycle consists of two consecutive time periods; a period where the system is up followed by a period of time when the system is down. This utilization of cycle time is an attempt to make SESAME more applicable to systems which are not evaluated solely by operating time. Some systems used by the U.S. Army are evaluated by the actual operating hours per day rather than operating 24 hours per day. For example:

```
    (---One Cycle---)(-------One Cycle-----------------)
UP     Repair     UP      Awaiting          Repair     UP
       Time               Parts             Time
----+---------+-----+-------------+--------------+------+---
   T1        T2    T3            T4             T5     T6
```

where Repair Time is part of downtime.

From the above diagram:

$$A_o = \frac{EU}{EU + ERT + ED}$$

where

EU = Expected Uptime per Cycle
ERT= Expected Repair Time per Cycle
ED = Expected Delays until Part is Available per cycle

This definition of availability is important when the cycle time occurs for a period where operating hours is less than 24 hours.

SESAME defines operational availability as: [Ref. 14]

$$A_o = \frac{MCTBF}{MCTBF + MTTR + MLDT} \qquad (2\text{-}3)$$

where

MCTBF (Mean Calendar Time Between Failures)
= Expected uptime per cycle
= (Mean Time Between Failures) MTBF/ OPHD
where OPHD=Operating hours per day

MTTR (Mean Time To Repair)
= expected repair time when spares are available

MLDT (Mean Logistics Delay Time)
= expected delay until a serviceable spare is available.

The demand support stockage policy requires the stockage of spare parts based upon the demand generated by failures of those parts within the operational environment. The problem with a system of sparing based upon demand support is that a reasonable availability cannot be readily attained. This is because of the criticality of specific items which have a low failure rate. These items fail infrequently but their failure has a significant effect upon the availability of the system. These are not adequately represented by the demand support stockage policy.

Figure 2.3 represents this occurrence for an equipment consisting of a mixture of demand and non-demand items [Ref. 18]. The figure shows that the demand support sparing

will yield a system availability that is not on the optimal availability curve. Therefore, any availability received

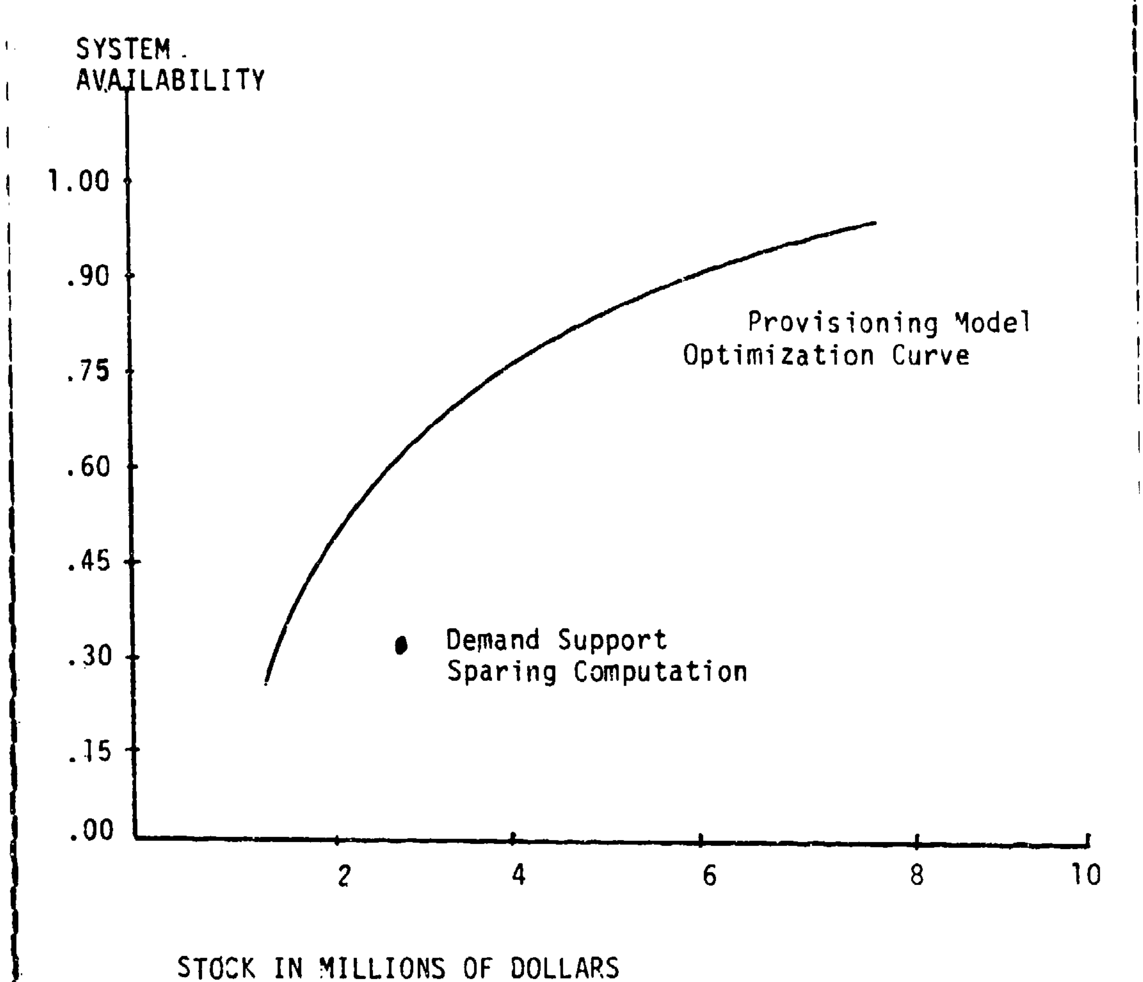


Figure 2.3 Demand Support Stockage vs. Sparing to Availability.

from this stockage policy will be less than that using a policy represented by the C-E curve. The curve in Figure 2-3 represents the lowest cost mix of spares to achieve

different system availabilities when the optimal stockage policy is used for all critical items within the system. The mixture provides a higher level of availability at the same approximate cost level.

There are several equipments that are well suited for the application of provisioning models:

1. Equipment having high operational availability requirements,
2. Equipment with low density deployment quantities,
3. Equipment designed with redundant configurations below the end-item indenture level [Ref. 18].

B. SESAME STRUCTURE

SESAME can handle both symmetric and asymmetric support structures. These structures define the number of units supported at each maintenance/supply echelon.

1. Support Structure

A symmetric structure is one in which each supply point within the system has exactly the same demand requirements as any other point on the same echelon level (Figure 2.4). An asymmetric structure is one in which each point within the system does not necessarily have the same demand requirements as any other point (Figure 2.5).

SESAME defines a non-vertical structure as one in which an echelon has a maintenance function but cannot fill supply requests. This represents the ability of a higher echelon unit to perform the required maintenance functions for a supported unit but not the supply function. In order for the demand generating unit to receive the required spare, it must pass the request to the next higher unit in its supply hierarchy (Figure 2.6).

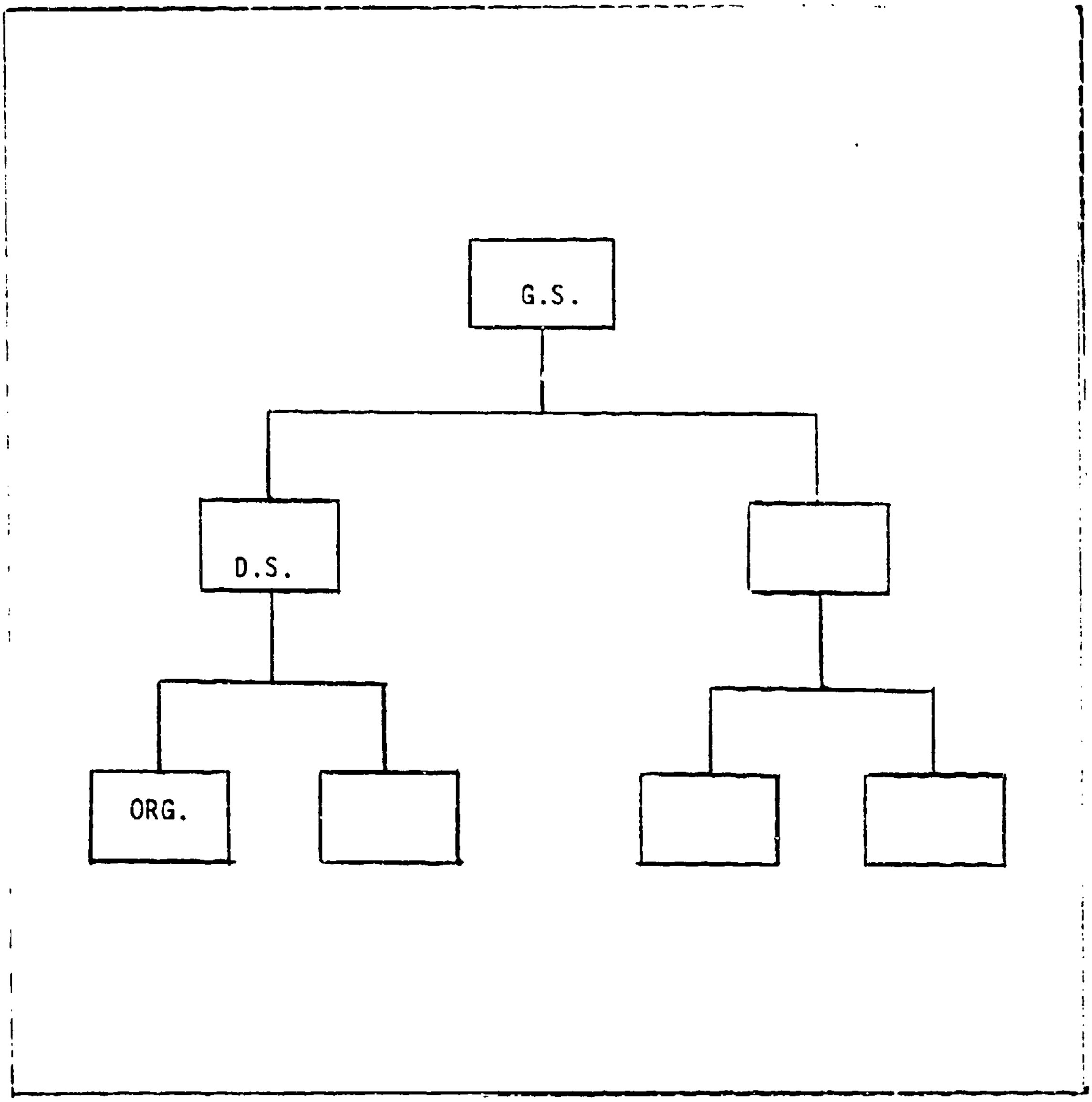


Figure 2.4 Symmetric Structure.

2. <u>System Structure</u>

Within SESAME an indenture level refers to the hierarchical role of a component within a system. A component may be an LRU or an SRU. For example, a second level component (SRU) is used to fix a first level component (LRU) which is used to fix an end item.

SESAME computes stockage on lower level components based upon economic considerations, but does not explicitly model their effect upon down time. By using

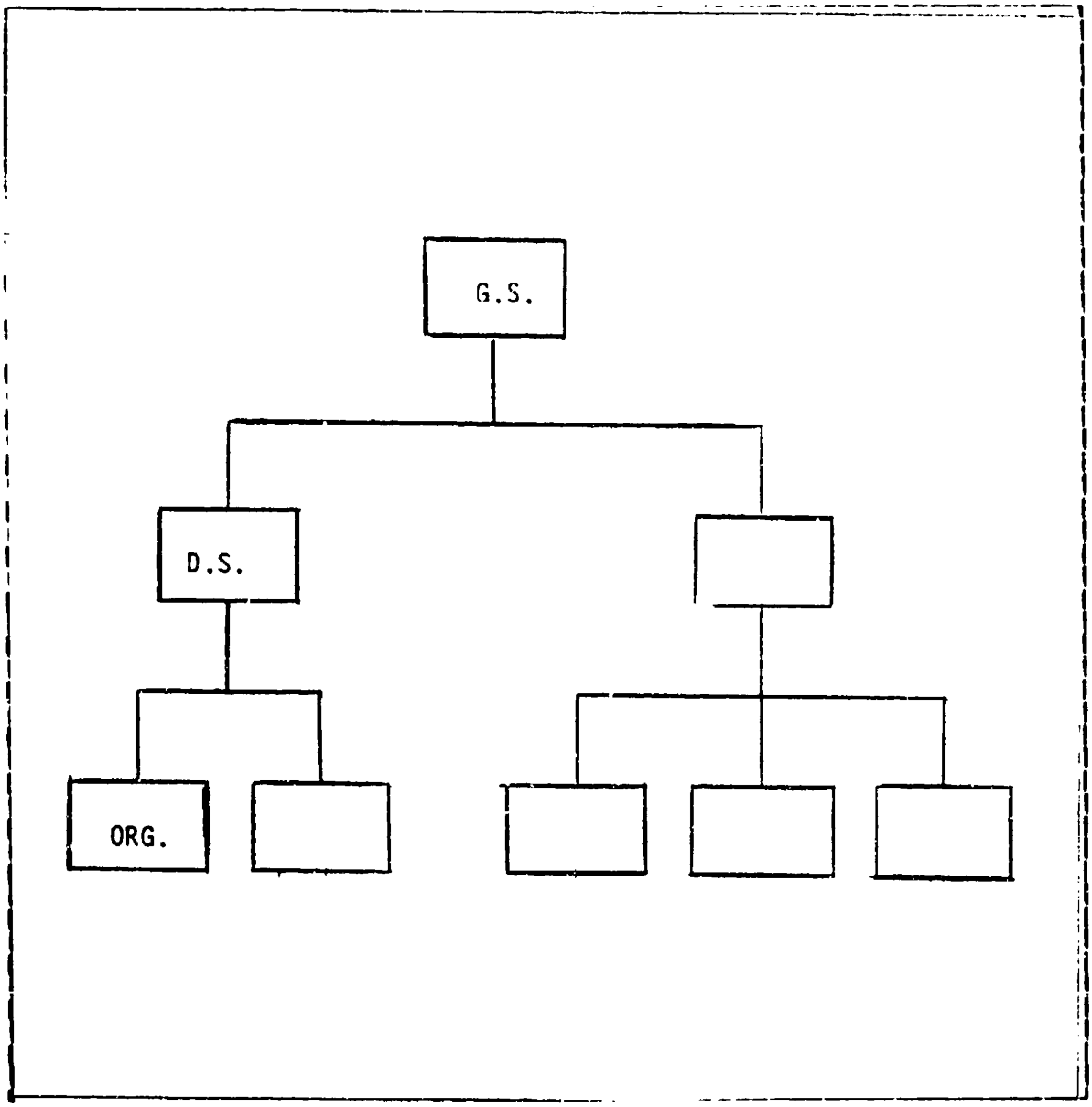


Figure 2.5 Asymmetric Structure.

Essentiality/Fault Isolation Module codes (ESS/FIM Code), the SESAME model determines whether to stock an item. If a

part is essential, it is always stocked. If a part is non-essential, it is treated as a non-LRU even if it is an LRU. As a non-LRU, the item has no effect upon determining

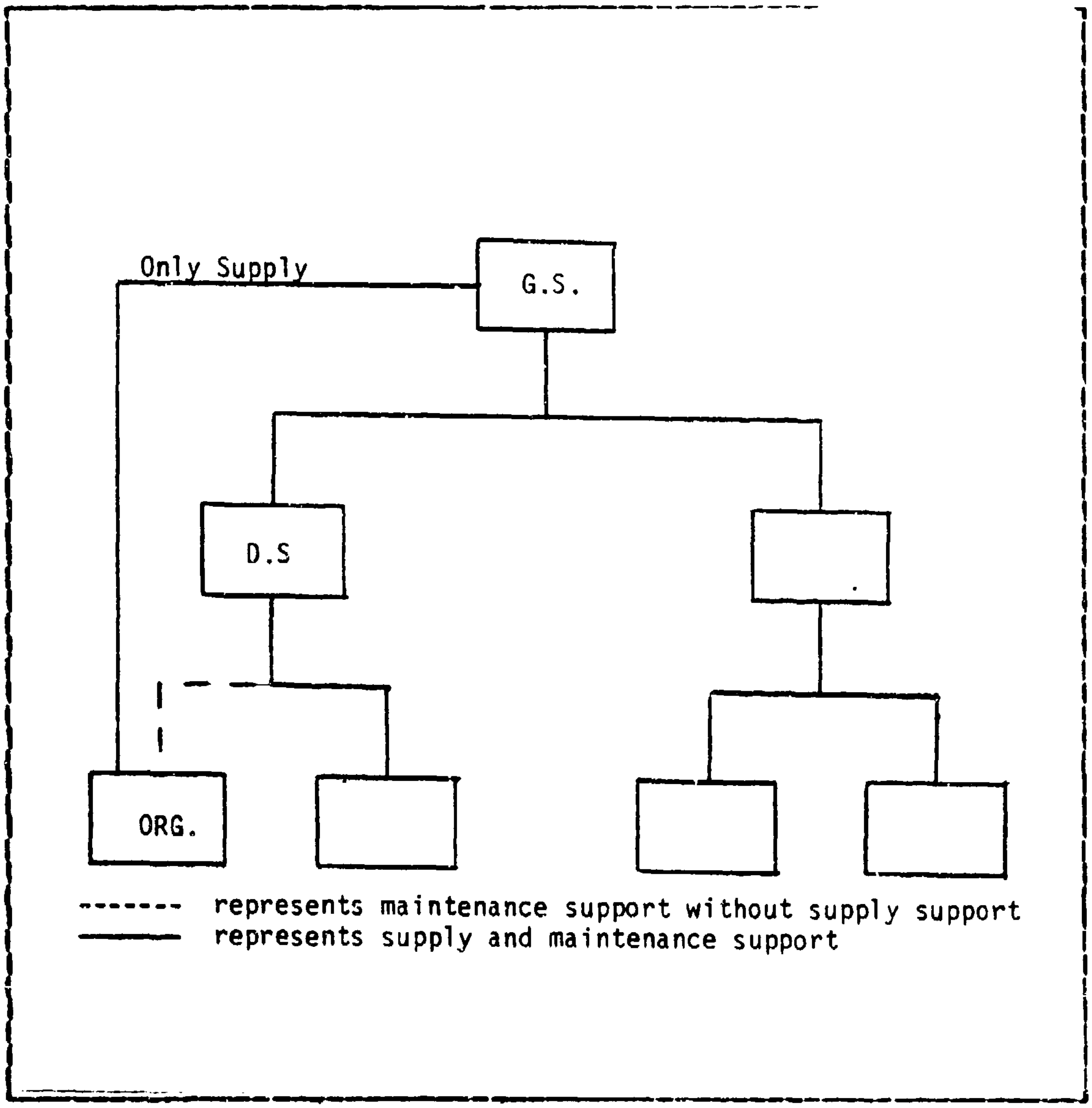


Figure 2.6 Non-Vertical Structure.

the total system operational availabiliy. Similarly, if an item is denoted a Fault Isolation Module (FIM), it requires

removal to determine failure. Items designated FIM are required to be stocked at least once at each echelon where the item can be removed and replaced. An item designated FIM can be a non-LRU item. A part can be designated FIM when it is an SRU if it is determined that the part must be removed in order to determine its status. If an item is essential it is required to be stocked, if the item is non-essential it is treated as a non-LRU even if it is an LRU. If a spare is FIM it must be stocked at least once at each echelon.

3. Maintenance Policy

SESAME recognizes that parts need not fail in order to be removed. It treats item failures as system failures. SESAME defines the level at which repairs can be conducted for specific spares. This is the Maintenance Task Distribution.

SESAME does not treat cannibalization at the present time. No steps are presently being taken to add this feature to the SESAME model.

4. Resupply Considerations

When an organization (ORG) is out of stock and requests a part from a direct support unit (DSU), the ORG wait will depend upon the DSU due-in date. Most multi-echelon models incorrectly assume that the ORG request will be delayed the full Order and Ship Time (OST) from Depot to DSU. SESAME uses the Two-Point improvement to METRIC [Ref. 19] and plans to adopt VARIMETRIC [Ref. 20] to the present software used within SESAME. The Two-Point improvement is a means to calculate time weighted backorders. This process is based upon the fact that the due-in to a stockpoint is represented as a Poisson Process compounded by a two point distribution of the mean. The two

points result from a simplified representation of the continuous distribution derived from the observed Order Ship Time. The two points represent an OST based upon the input OST, which assumes no delay, and the OST augmented by the average time of backorder, given that a backorder exists.

F. MATHEMATICAL OVERVIEW

SESAME can handle large problems very quickly by utilizing a Lagrangian multiplier optimization technique [Ref. 21]. The basic optimization objective of the model is [Ref. 22]

$$\text{Minimize} \sum_{I} \sum_{J} S(I,J) \times N(J) \times UP(I)$$

$$\text{Subject to } PNORS < \alpha$$

where

S(I,J)	=amount of item I stocked at an echelon J unit
N(J)	=number of units stocking spares at echelon J
UP(I)	=unit price of item I
PNORS	=% of time system is down due to unavailability of a component
α	=maximum permissible PNORS

The PNORS constraint is modelled by restating the problem as follows:

$$\text{Min} \sum_{I} \sum_{J} S(I,J) \times N(J) \times UP(I) + \sum_{I} \sum_{J} EB(I,J) \times RTD(I,J) \times N(J) \times BPC(I) \quad (2\text{-}4)$$

where

EB (I,J)	= expected amount of item I backorderd at echelon J
RTD(I,J)	=replacement task distribution percent
BPC(i)	=backorder penalty cost

(The replacement task distribution is a standard Army provisioning term which represents where the component is removed and replaced; for example RTD (I,1)=100% means that the component is solely used by the element at the organizational echelon.)

1. <u>Optimization Technique</u>

a. Single Item Optimization

The objective of single item optimization is to determine upper bounds for the optimum stockage quantities, then dynamically reduce these bounds based upon potential optimum solutions as they are evaluated.

The procedure used is based upon determining the lowest and highest values of total cost where total cost is the sum of of backorder and inventory costs, given stockage at a specific echelon J, and inventory cost is charged only for stock at echelons 1 thru (J-1).

$$(S_n^*)(UP) + TC_{n-1}^*(S_n^*) < (0)(UP) + TC_{n-1}(0) \qquad (2\text{-}5)$$

where S_n^* =Stockage at echelon J

$TC_{J-1}^*(S)$ =Lowest possible sum of backorder and inventory costs, given $S_n^* = S_n$.

UP =Unit Price.

S_J^* =Optimum stockage at echelon J.

This implies that as upper echelon stock is raised, delays to lower echelons drop and so do echelon costs. For the upper echelon n, all values for S are tried until an upper bound on S is reached. At the lowest echelon, cost is a convex function of S therefore the bounding procedure is not necessary. For each value of S_n^*, a value of $TC_{J-1}^*(S_n^*)$ is detemined.

b. Multi-Item Optimization

Multi-Item Optimization within SESAME is computed using the A_o formula to minimize inventory investment subject to Mean Logistics Downtime (MLDT).

$$MLDT = \frac{\sum (MLDT_i / MCTBF_i)}{\sum (1/MCTBF_i)} \qquad (2\text{-}6)$$

and

$$EMF = \frac{A_o}{MCTBF}$$

where

EMF = Effective Maintenance Factor, the number of LRU removals per end item per year.

Relative removals are proportional to relative failure rates, therefore,

$$EMF_i = \frac{(EMF)\ (1/MCTBF_i)}{1/MCTBF} \qquad (2\text{-}7)$$

substituting the formula for EMF , in the formula for MLDT

$$MLDT = \frac{\sum (MLDT_i)\ (EMF_i)}{EMF}$$

where

$$MLDT_i = \frac{TWB_i}{(EMF_i)\ (N)} \qquad (2\text{-}8)$$

where

N = the number of weapon systems supported

TWB_i = the expected time weighted backorders for the ith component.

Therefore

$$MLDT = \frac{TWB_i}{(EMF)\ (N)} \qquad (2\text{-}9)$$

2. Operational Availability

The Operational Availability (A_o) calculated within SESAME is a function of the expected backorders of the components, the yearly removal rate of each component, the average time between system failure, and downtime while system is in repair. In determining A_o, only essential LRU's are considered.

SESAME defines operational availability in terms of MCTBF, LDT and MTTR. This formula has the advantage that it can estimate the system MCTBF from the component failure factors without depending upon the MCTBF of the indiviual items.

$$A_o = \frac{MCTBF}{MCTBF + MLDT + MTTR} \qquad (2\text{-}10)$$

$$SA = 1 - \frac{MLDT}{MCTBF + MLDT + MTTR} \qquad (2\text{-}11)$$

Given that MTTR is very small,

$$SA = MCTBF/(MCTBF + MLDT) \qquad (2\text{-}12)$$

where

A_o = Operational Availability, hours the system

is up as a per cent of total hours.

SA = Supply Availability, per cent of hours system is not down due to unavailability of a component.

MLDT= Logistics Down Time, average time to get an LRU when needed.

SESAME is an analytic computer model that can be run interactively or in a batch mode. SESAME can handle four echelons but it presently optimizes three. One of the major products of the SESAME model is the Mean Logistics Delay Time (MLDT) which is the weighted average of the delay for the LRU spares. Availability is determined but it is through MLDT that spares provisioning affects A_o. SESAME allocates a fixed budget to achieve the highest possible A_o. Since MLDT is the only factor affected by stockage decisions, achieving a maximum A is equivalent to determining a minimum MLDT for a fixed budget.

$$MLDT = \frac{1-A_o}{A_o} \times MCTBF - MTTR \qquad (2-13)$$

3. Pipeline Quantities

Pipeline quantities are the basis for stockage. The pipeline is the amount of spares to be stocked at each echelon based upon demand, the percent of repairs to be performed at that echelon, demand causing a request from the part supplier, and the order ship time. The general formula for pipeline at a stock point is : [Ref. 23]

Spare stockage according to pipeline=

$$(DDR) \times (PRS) \times (RCT) + (DDR) \times (DCO) \times (OST + OLD) \qquad (2-14)$$

where

DDR = Daily Demand Rate

PRS = % of demand to be repaired at stockpoint

RCT = Repair Cycle Time

DCO = % of Demand Causing Order from supplier

OST = Order and Ship Time

OLD = Operating Level Days

The nature of the pipeline makes the following input data critical:

- The failure factor is the most critical input.
- A change in the maintenance task distribution will result in repairs of LRU's closer to the user which will cause lower demand rates.
- A change in the replacement task distribution will result in replacement of non-LRU's at higher echelons which will eliminate some of the pipeline required for those spare parts.
- Changes in Order Ship Time affect all spares at that echelon.

4. The Stockage List Method

The Stockage List Method is used when the input data contain detailed information about the number, type and specifications of the parts. SESAME will produce the stockage cost for the sample required to achieve a target availability that the user has entered as an input.

SESAME determines the retail stockage requirements in terms of two retail budgeting approaches. One approach is to take the total initial issue funds required to support all operational items at the end of a deployment year, and then subtract previously budgeted initial issue dollars. This approach is called the cumulative approach to retail budgeting. The other method is to consider only the requirements of units that come into existence during the respective deployment year. This is called the incremental

approach to retail budgeting. The type of retail approach used in the SESAME model should closely resemble the actual plan for deployment visualized within the budget.

In determining the budget, SESAME divides stockage into wholesale and retail requirements. The wholesale requirement covers the consumption of spares due to washout and the impact of the depot level repair cycle.

SESAME defines consumption as:

consumption =

$$\frac{(BDENS+DENS)}{2} \times (BYEARS) \times (\text{washouts/item/year}) \qquad (2\text{-}15)$$

where

BDENS =Beginning density (units of program)

DENS =Ending density (unitsof program)

BYEARS =Years in budget horizon

G. SUMMARY

In summary, SESAME can allocate spares to units at different echelons based upon a fixed budget. By defining the input parameters to the pipeline, an analysis of stockage policy is possible. By using multiple iterations of SESAME with different supply and maintenance distributions, the user can determine the optimum stockage policy to use at a given budget and required operational availability. Deployment of spares according to the budget can be modelled and estimates of total system cost can be generated when all system knowledge is not available. SESAME produces output which allows the user to know where parts are allocated and how much the total cost of spares will be at each echelon for a target level of availability or total cost.

III. THE OPUS VII MODEL

A. BACKGROUND

The OPUS model was initially developed (1970) by Systecon AB, Sweden, as an in-house sponsored project for the Swedish government. The improvements that have been incorporated into the OPUS model since then have been made as a result of contracts from the Material Departments of the Swedish Defense Material Administration. [Ref. 24].

OPUS was created as a steady-state model for optimal allocation of LRU's and SRU's in a maintenance organization. The original intent of the model was to serve as a computer-based aid for initial provisioning. Continued refinements have enabled the OPUS model to deal efficiently with the following types of problems [Ref. 25]

- -Initial procurement of spares (allocation of spares within the organization),
- -Reallocation of a given assortment of spares,
- -Replenishment procurement of spares,
- -Reallocation of a given assortment and initial procurement of new types of spares, and
- -Cost-Effectiveness evaluation of alternative maintenance and supply concepts and alternative system configurations.

OPUS is designed to use any or all of four different measures for evaluating the effectiveness of a problem solution. These Measures of Effectiveness (MOE) are:

a) System operational availability (A_o).

b) Probability of successful mission performance.

c) Risk of shortage when a spare is demanded.

d) Mean waiting time for a spare (computed for each level of the maintenance organization).

B. CHARACTERISTICS

The original design of the OPUS model placed emphasis upon the ability of the model to be efficiently used as a study tool. This design concept provided the OPUS Model with several special characteristics:

- An ability to handle LRU's and SRU's in a hierarchic maintenance organization with an arbitrary number of echelons,
- A means by which to choose different measures of effectiveness,
- A means to run multiple levels of investment and spares allocation,
- A computer methodology which is not costly to run and, therefore, enables extensive studies of possible solutions, and
- A capability to handle different systems simultaneously.

As with most computer models, the value of the OPUS VII outputs is directly related to the quality of the input data. OPUS VII has the ability to perform sensitivity analysis upon its input variables. In this manner, the user can determine the importance of each input and the amount of precision that the input data requires in order to provide a valid result.

OPUS VII is user friendly. The output is designed to assist an analyst and the OPUS output will provide him with:

- Graphs depicting how the MOE is related to level of investment,
- Tables of different levels of investment, showing number of each type of spare to be purchased, and the best location for the storage of these spares,
- Tables reflecting the distribution of initial investment costs among the different levels of

the organization, and
- An overall cost-effectiveness curve.

C. ASSUMPTIONS

The algorithms used by the OPUS VII Model are based upon the following assumptions:

- The demands are Poisson distributed.
- Mean values of turn-around time are known.
- Failures are independent of other item failures and are known.
- Repair times are statistically independent and are known.
- No waiting times at the maintenance facilities (no batching of repairs).
- As soon as a spare is requested, a replacement spare is ordered (an (S-1,S) stockage policy).

1. Optimization Techniques

OPUS VII utilizes two types of optimization techniques. The techniques are defined within a macro and a micro structure. Both structures can be described as imbedding methods. The microstructure can also be viewed as a dynamic programming method. The macrostructure divides the problem into multiple subproblems. Each subproblem is restricted to no more than 1500 independent variables. By utilizing both methods, OPUS can handle very large and very complex problems.

The concept of cost-effectiveness is a major part of the optimization procedure used by OPUS. The measure of effectiveness is considered as a function of the stock levels, given all relevant information concerning the activities and support flow of the organization. The measure of cost is the total investment in LRU's and SRU's which are

to be distributed in the organization. If a specific cost constraint is given, it is possible to determine values of

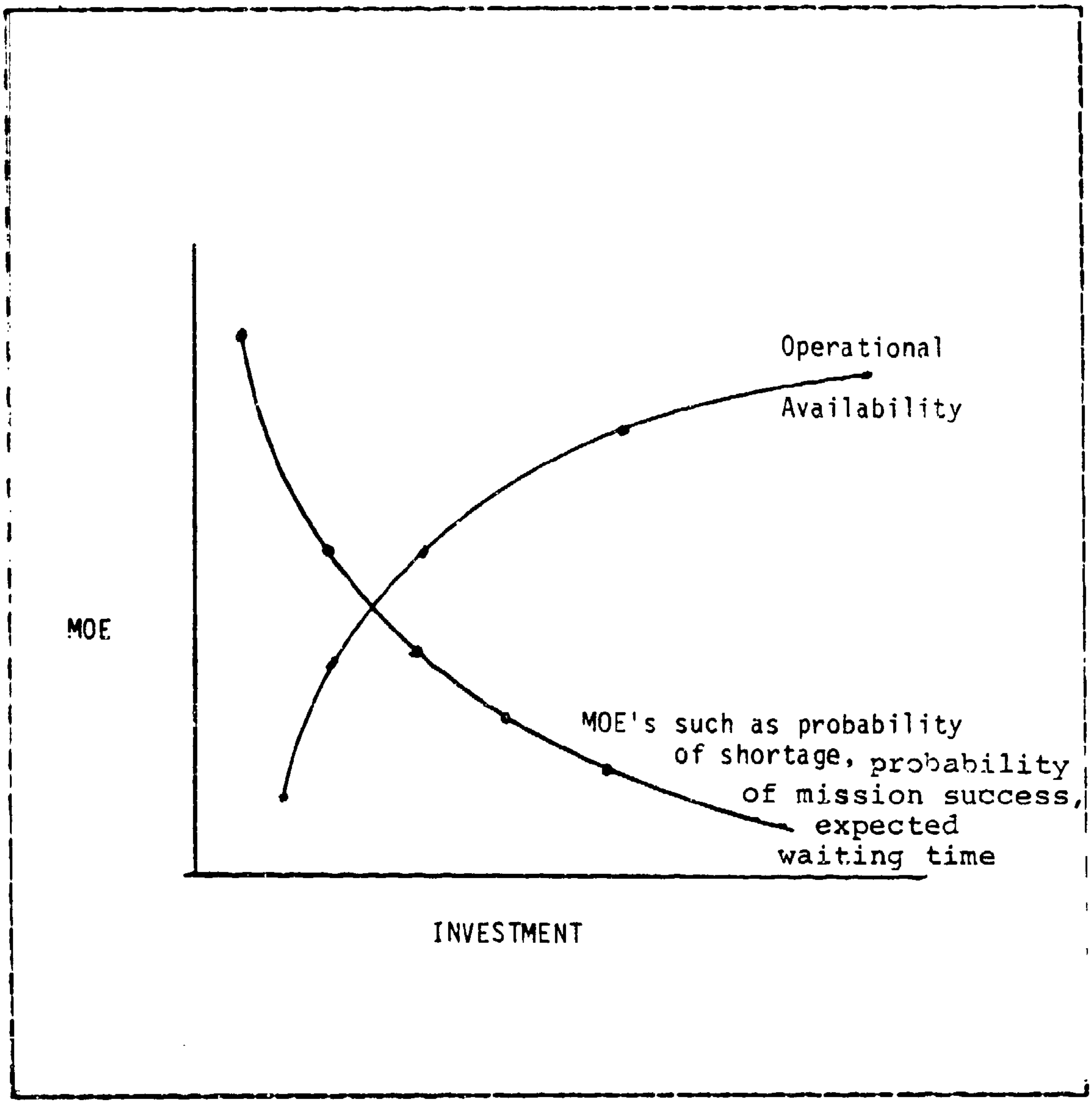


Figure 3.1 C-E curve MoE as a Decreasing Function of the Investment.

spare stock levels where the chosen measure of effectiveness is optimized (Figure 3.1) [Ref. 24].

D. SYSTEM STRUCTURE

OPUS VII was designed to handle systems using Line Replaceable Units (LRU's) and Shop Replaceable Units

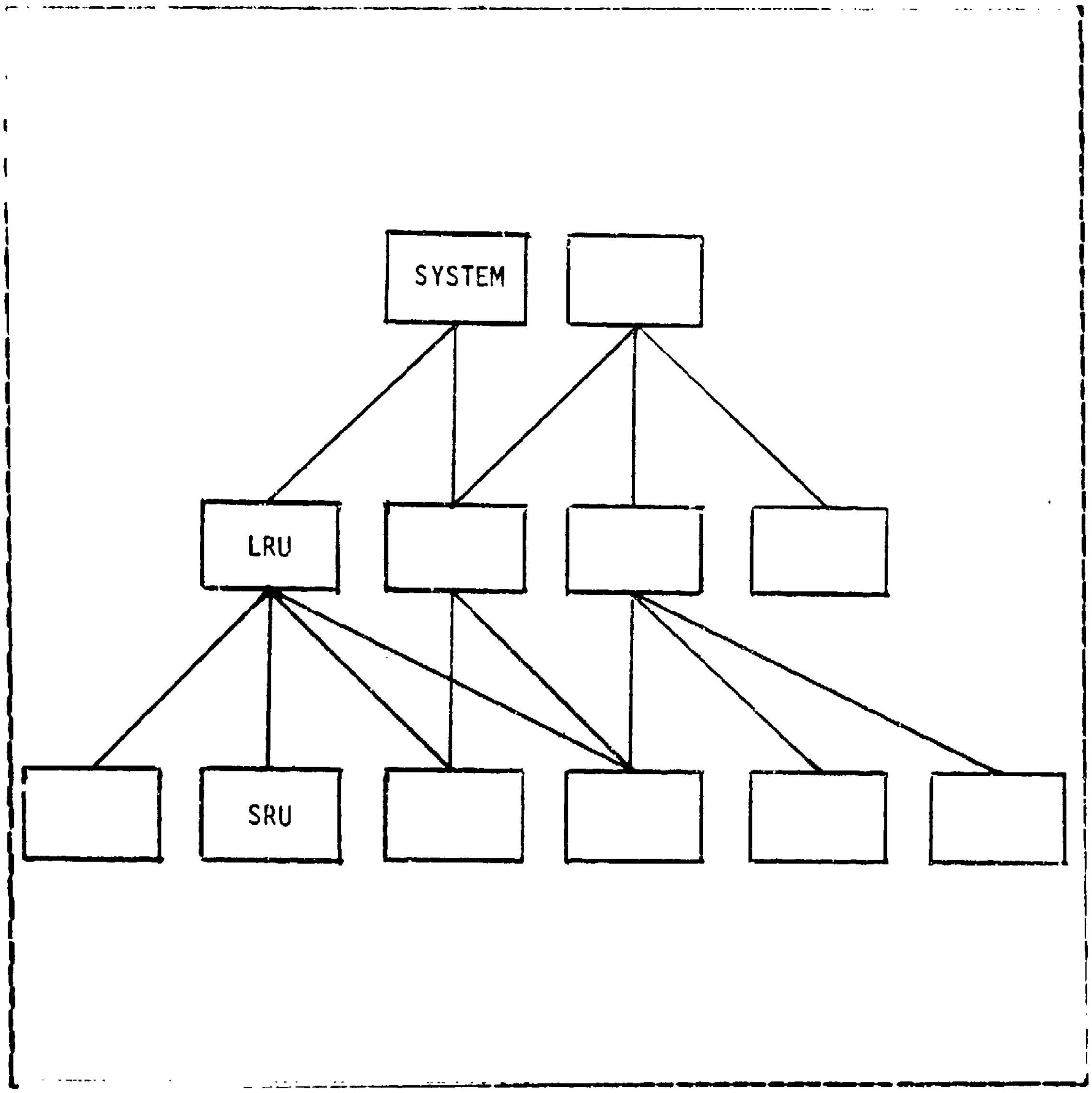


Figure 3.2 OPUS System Structure.

(SRU's). The ability of OPUS to handle more than one system at a time and the ability to handle additional system

indentures requires that specific input data be available. This input data must contain:

SRU Data
- number of different types of SRU's
- for each SRU type, replacement rates and unit prices

LRU Data
- number of different types of LRU'
- for each LRU type, replacement rates and unit prices
- for each LRU type modularized into SRU's, identification of those types of SRU it contains, number of units of any such types.

System Data
- number of different types of systems
- For each system type: identification of those types of LRU it contains, number of units of every such type.
- System Mean-Time-Between-Failure (MTBF).

Figure 3.2 depicts an example of the structure of a system [Ref. 24].

1. Structure for the Support Organization

OPUS VII places very few constraints upon the maintenance and support organizations that it models. The only major requirement is that the support structure be built in a hierarchical way. By hierarchical it is meant that every unit on one level (echelon) will be supported by a unit or units of a higher level (echelon). This structure allows for the flow of spares between stations at different levels by the use of "dummy" stations. "Dummy" stations are added to the hierarchy and they have turn-around-times but zero stockage levels (Fig 3.3). OPUS also allows lower echelon units to be supported by more than one upper echelon unit. This support system is done by defining the

probability that a lower echelon unit s supported by a given upper echelon unit (PNYPR).

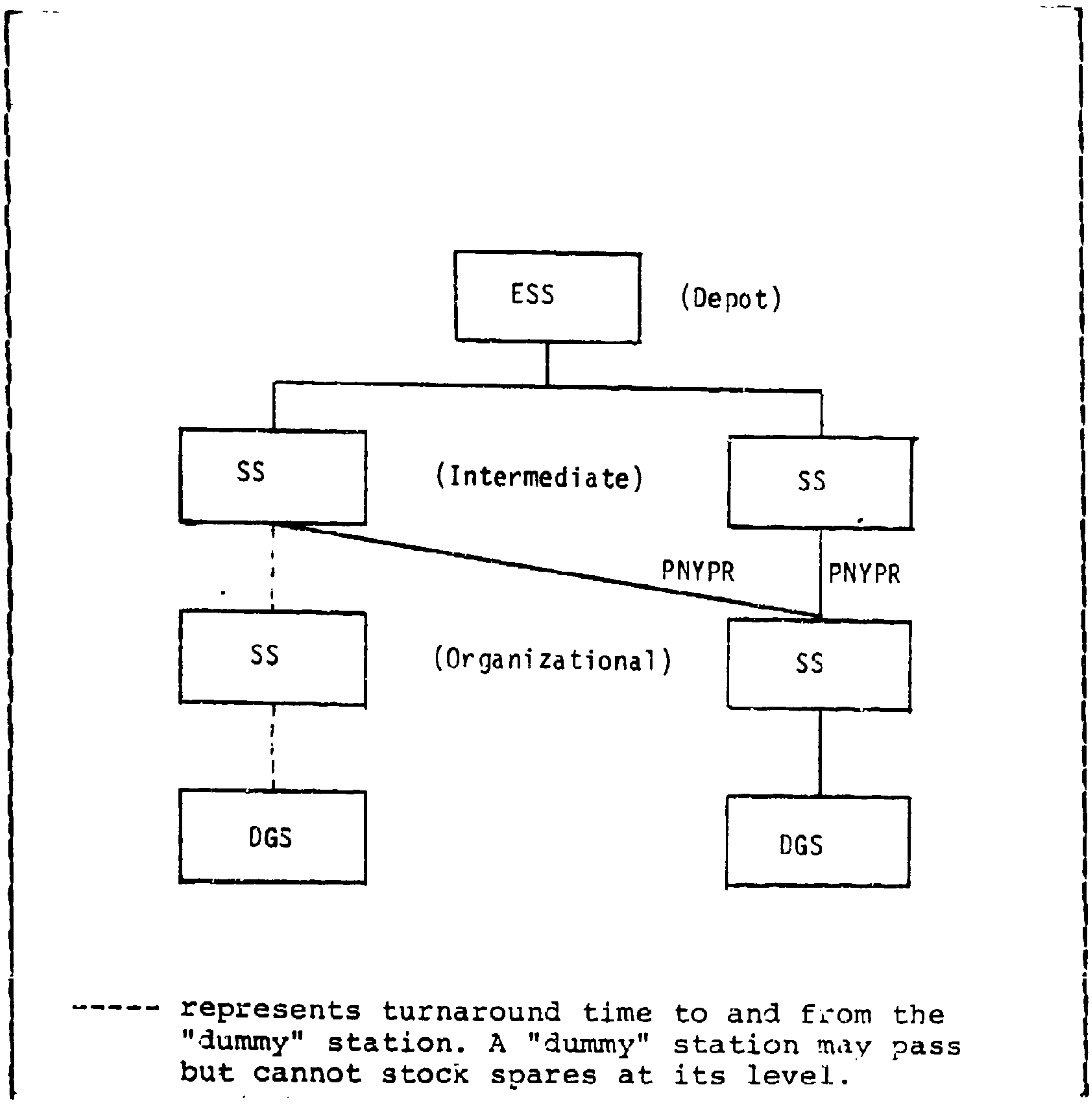


Figure 3.3 OPUS Support Structure.

a. Elements of the Support Structure

To model the support flows, OPUS uses a number of basic elements. These basic elements are combined with a set of rules which define the way in which basic elements are put together. The basic elements are:

-station
-identifier
-address
-demand
-support

b. Stations of the Support Structure

There are three stations within the support organization that are built up by the basic elements. These stations are:

a) End Support Station (ESS) - corresponds to depot(maintenance) level, and may include stockage facilities.
b) Support Station (SS) -corresponds to intermediate or organizational level of maintenance, and may include stockage.
c) Demand Generating Station (DGS)-the organizational user.

c. Rules for Creating Support Systems

OPUS enables these stations to be combined arbitrarily, forming a support system. This support system can be handled by OPUS as long as the following rules are followed:

-Each DGS must be supported by one and only one SS (at Organizational level).
-Each SS (at the Organizational level) must be supported by one or more SS (at an intermediate level) or ESS.

An SS may exist at the organizational level and serve as the unit that stocks spares at that echelon, this unit is separate from the DGS.

- There exists at least one ESS and at least one DGS.
- A specific demand, and its resultant demands, must not loop back and regenerate another demand. This refers to the fact that if a spare is not available at the next higher echelon and a due-in is established, the lower echelon unit will receive notification that the part is due-in and should not re-order the part.

d. Required Support Station Input Data

In order to run OPUS, the following Support Station data are required:

- A demand history which identifies which stations initiated which demands,
- Identification of which items are allowed to be kept in inventory,
- The time to repair an item required at a station, and
- Time to receive a spare from the next higher SS when no shortage exists.

2. The Macrostructure

A given problem is divided into a number of independent subproblems. The number of independent variables within each subproblem is dependent upon the type of computer used [Ref. 26]. By solving subproblems, OPUS comes up with a cost-effectiveness curve. By performing a marginal cost analysis upon the results of each subproblem, a final C-E curve can be produced.

3. The Microstructure

The system is defined in terms of the set S of all independent variables, where

$$S = S_1 \cup S_2 \cup \ldots \cup S_k$$

and the subset S is independent of all other subsets. The variables of Sk are mutually independent.

For example,

S_1 = (All SRU's at the ESS)

S_2 = (All LRU's at the ESS)

(All SRU's at SS , SS , SS)

S_3 = (All LRU's at SS level)

(All SRU's remaining at SS level)

S_4 = (All systems of DGS1, DGS2,...,DGSk)

The optimizing procedure calculates a C-E curve of the subset S1. Subsequently, a C-E curve is determined for subset S2. This is possible because S2 depends only upon S1. This procedure is continued for all subsets. This procedure produces stockage levels for the entire space S.

B. MATHEMATICAL OVERVIEW OF OPUS VII

1. Opus Optimization Algorithm

The algorithm used by OPUS VII to determine an optimum solution is defined for problems in general and then modified to handle more difficult (multi-level) type problems. The algorithm determines a C-E curve in terms of a subset S. The subset S is denoted

$$(C_{1,l} \quad E_{1,l}) , \; l=1,2,\ldots,L \qquad (3\text{-}1)$$

where

C(i) = unit price per item

E(i) = measure of effectiveness l represents the corresponding stock levels.

The total demand rate of S is defined as

$$DTOT = \sum_{i=n_1+1}^{n_2} M(i)\ D(i) \qquad (3-2)$$

where

M(i) = multiplicity factor used in describing symmetries in maintenance organizations.

D(i) = Demand Rate

and the Turnaround Time (TAT) is

$T(i),\ i=1,2,\ldots,n_2.$

where

$T(i) = TO(i) + \sum p(i,j)\ E(j)$

TO(i) = a constant independent of stockage levels.

E(j) = Expected waiting time at position j.

P is the triangular transition matrix (p(i,j) j=1,2,...n) describing the step transition probabilities between positions of S (Figure 3.4)

The first point of the Cost-Effectiveness Curve is l=1

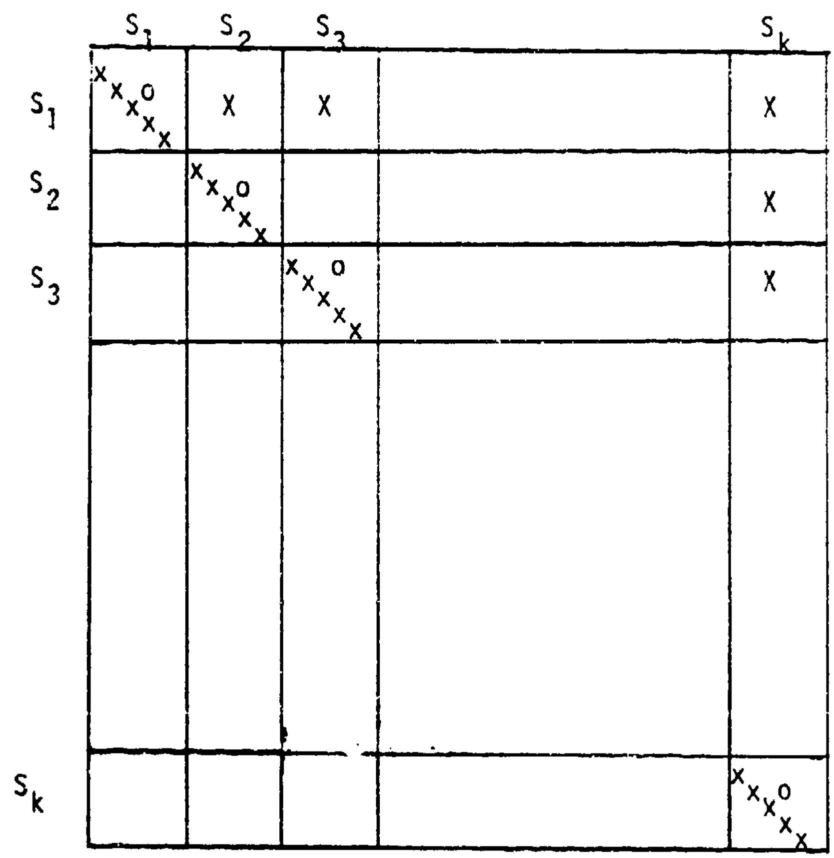
$C_{1,l} = 0$

$$E_{1,l} = \frac{M(i)\ D(i)\ T(i)}{DTOT} \qquad (3-3)$$

with $N_{1,l}(i) = 0$

$E_{1,l}(i) = T(i)$ where $i = n_1+1,\ n_1+2, \cdots n_2$.

From the values of i, OPUS VII determines the Lagrangian multiplier [Ref. 21]



X denotes nonnegative elements
0 denotes zero elements

Figure 3.4 The Transition Matrix.

$$\lambda(i) = \frac{Q(i)}{C(i)}$$

where

$$P(i) = \exp(-D(i)\ T(i))$$

$$Q(i) = 1 - P(i) .$$

These Lagrangian multipliers are sorted in decreasing order

$$I = (I(i),\ j = n_1 + 1,\ n_1 + 2,\ \cdots\ n_2) .$$

The optimization procedure starts by investing $M(j)$ units at position number j of subset S_1, where

$j = n + I(1)$.

Therefore, the next point in the curve is

$l = l + 1$

$$C_{1,l} = C_{1,l-1} + C(j)\ M(j) \qquad (3\text{-}4)$$

$$E_{1,l} = \frac{E_{1,l-1} - M(j)\ Q(j)}{DTOT}$$

and the individual values are

$$N_{1,l}(j) = N_{1,l-1}(j) + 1 \qquad (3\text{-}5)$$

$$E_{1,l}(j) = \frac{E_{1,l-1}(j) - Q(j)}{D(j)}$$

From these OPUS calculates

$$P(j) = \frac{P(j)\ D(j)\ T(j)}{N_{1,l}(j)} \qquad (3\text{-}6)$$

$$Q(j) = Q(j) - P(j)$$

$$\lambda(j) = Q(j)\ C(j)$$

The calculations are stopped when total investment is greater than a prescribed upper limit or when the waiting time is smaller than a prescribed lower limit. (Fig.3.5)

2. Measures of Effectiveness

OPUS uses four measures of effectiveness, expected waiting time, availability/number of available systems (NORS), probability of a shortage given a demand, and probability of a successful mission.

a. Operational Availability

The availability determined in OPUS is associated with the waiting time at the operational level of the organization. OPUS defines availability as

$$E(i)=1/(1+D(i)(T\ (i)+\sum_{j=1}^{n_k} p(i,j)E(j))) \quad \text{for } i=n+1,\ldots,n_{k+1} \quad (3-7)$$

where $E(j)$ is the expected waiting time for $j \leq n_k$.

The Expected Waiting Time (EWT) is the average time needed to satisfy a demand. Availability may be rewritten

$$A_o = MTBF/MTBF+EDT$$

where EDT is the average downtime per failure.

The expected number of non-available systems (NORS) is found

$$NORS = N \times (1-A_o) \qquad (3-8)$$

where N is the total number of systems.

b. Probability of a Shortage

The probability of shortage refers to the inability of a unit to satisfy a demand within a certain amount of time due to a shortage in stock. This is represented

$$E(i) = \sum_{m=0}^{\infty} P_{N(i)+m}(TAT(i)\ D(i)) \qquad (3-9)$$

where i is a position number of a given subset S : i=n +1, n +2,...,n and the turnaround time is

$$TAT(i) = TO(i) + \sum_{j=1}^{n_k} p(i,j)E(j) \qquad (3-10)$$

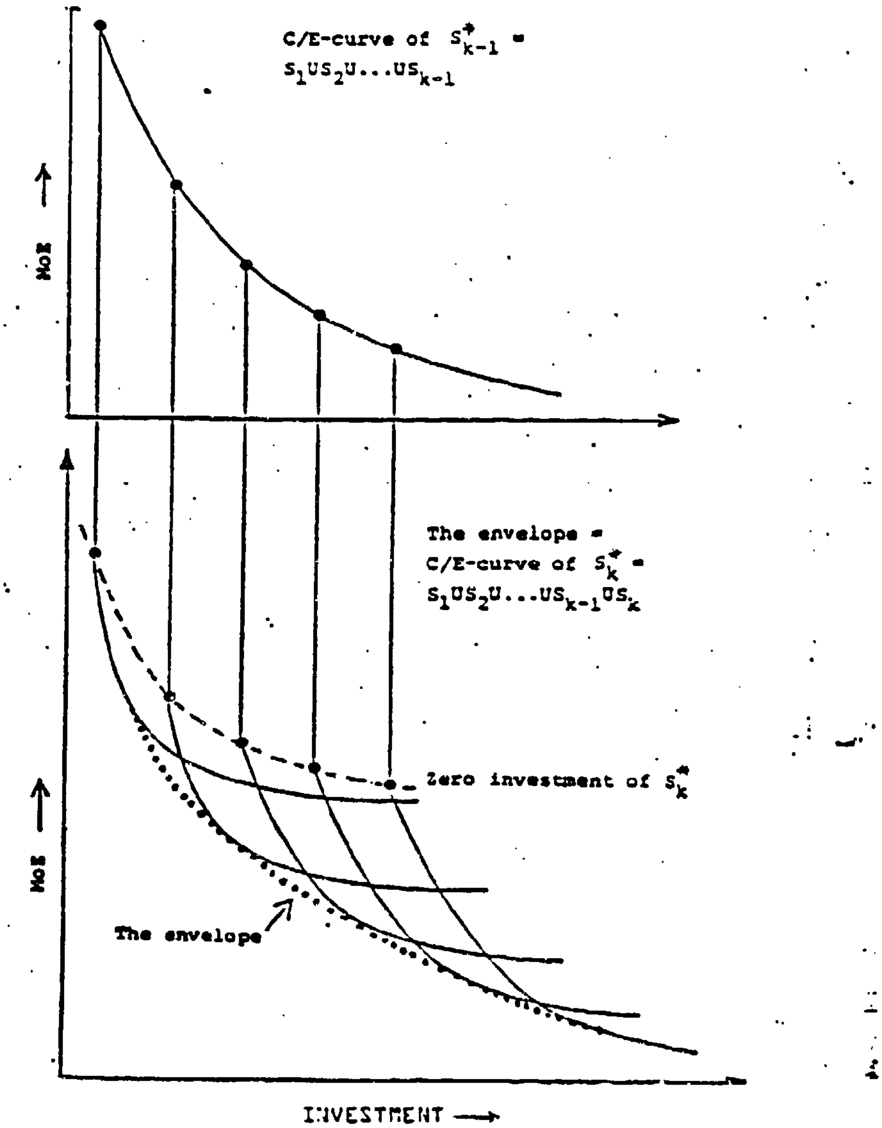


Figure 3.5 OPUS Optimization Curves.

where E(j) is the expected waiting time at the position number j, where $j \leq n_k$.

T=shortage in stock, lasting less than T units of time from the point the demand was generated from.

$$N^*(i) = N(I) + \Delta N \tag{3-11}$$

$$N = \begin{cases} \text{if } T > TAT(i) & \infty \\ \text{integer part of } \left[(N(i)\ T/(TAT(i)-T)) \right] \\ \text{if } T < TAT(i) \end{cases}$$

Then the probability of shortage given demand can be written as

$$\hat{E}(S_K) = \sum_{j=n_K+1}^{n_{K+1}} p(i)\ E(i) \tag{3-12}$$

where

$$p(i) = \frac{M(i)\ D(i)}{\sum_{j=n_K+1}^{n_{K+1}} M(j)\ D(j)} \tag{3-13}$$

c. Probability of a Successful Mission

The probability of successful mission refers to the periods of time when a unit may not be connected with the rest of the maintenance organization, such as a ship at sea. The weighted probability of successful mission performance is given as

$$E(S_{K-1}) = \prod_{i=n_{K-1}}^{n_K} PSM\ (N(i), D(i), MT(i), Q(i))^{m(i)} \tag{3-14}$$

where PSM (N(i), D(i), MT(i),Q(i)) is the probability that there will be no occurence of a demand that is unsatisfied during the mission time MT, provided that the mission started with no more than N(i) units of spares. Q(i) is the probability that a demand could not be satisfied from stations supporting the mission.

$$Q(i) = \sum_{j=n_{K-2}+1}^{n_{K-1}} p(i,j)\ E(j) \tag{3-15}$$

where

p(i,j) is the probability that position i is supported from position j, and

$E(j)$ is the probability that a demand could not be satisfied within a specified time between missions (TBM) at position j.

PSM is defined as

$$PSM = \sum_{n=0}^{N(i)} P_n^o \sum_{m=0}^{n} P_m^o \,(D(i)\ \ MT(i)) \qquad (3\text{-}16)$$

where P is the steady state probability that a ship will start a mission with n units of item i on board. The probabilities p , n=1,2,...,N are the probabilities of a Markov chain with the steady states -1, 0, 1,..., N and with the following transition probabilities

$$P(N,N) = P_o + (1-P_o)(1-Q)$$

$$P(N,N-1) = (1-P_o)Q$$

$$P(n,n+1) = P_o(1-Q)$$
$$P(n,n) = P_oQ + (1-P_o)(1-Q) \qquad 0 \leq n < N$$
$$P(n,n-1) = (1-P_o)Q$$

$$P(-1,0) = 1$$

where P = probability that no demand for that item has occurred during the mission.

3. Allocation of Spares

The basic procedure used by OPUS is the initial allocation of LRU's at the highest (Depot) level. The LRU giving the best return on investment (in terms of MOE per dollar) is procured first. The next highest return on investment determines which LRU is procured next. This pattern is continued until a level of investment is reached or a specific MOE is obtained. The procurement of LRU's creates a C-E curve. The next step is to procure SRU's at the highest level and LRU's at the next highest level. By

choosing points (maximum of fifty) from the original C-E curve, OPUS determines the marginal return on investment of each item and procures the one with the highest return per dollar given previous investments. This procedure continues for each echelon until LRU's for the maintenance level directly supporting the system is stocked. From this procedure OPUS gives the user,

- optimal value of the MOE, for each level of investment,
- optimal assortment of spare parts by investment level, and
- optimal stockage policy, based upon each assortment of spares.

OPUS is designed to keep the number of calculations to a minimum. By choosing a representative number of points on the C-E curve, computer time is saved. An example of this is the selection of only equally spaced points on the investment interval. A similar means to save computer time is to separate storage of stock level distribution and candidates for final solution. OPUS calculates which points are on the C-E curve, so when it determines candidates, it knows beforehand which candidates will be final points on the C-E curve. When the final point is achieved the corresponding stock level is paired to it.

The OPUS computer program can handle a maximum of 500 different LRU's and SRU's. The number of stock points and different types of spare parts cannot exceed 1500.

F. SUMMARY

In summary, OPUS has the capability of determining where spares will be stocked in order to optimize a specified MOE. A user can specify boundaries for the decision and the model will optimize the stockage policy according to those boundaries. By using the various MOEs, the user can identify

stockage problems that will require specific attention (for example, minimum stockage at user level).

IV. TEST PROBLEMS USED FOR THE NUMERICAL EXAMPLES

A. INTRODUCTION

In order to compare the SESAME and OPUS VII provisioning models, a problem structure was chosen to enable similar data to be evaluated. The different algorithms that SESAME and OPUS VII use to optimize item stockage required a thorough evaluation and of each model's input data requirements. By studying the input data, similarities were identified and differences were noted.

To evaluate both models, two test sets of data were employed. One set of data was created for OPUS VII, while the other set was created for SESAME. Data for the sample inputs are included in Appendix A and Appendix B. These sets of data were chosen because they both represented asymmetric structures which are representative of viable systems and each set of data could be translated into the other model's data input structure. Inputs that were not applicable to both models were originally given their default values. The test sets were run for both models and the outputs compared as shown in Figure 4.1 .

B. OPUS VII DATA

The OPUS VII data were derived from earlier OPUS VII research and edited in a manner that made it more compatible with the SESAME model [Ref. 26]. The system breakdown used consisted of a single system (because SESAME only runs one system at a time) containing six LRU's and eleven SRU's. The system breakdown is depicted in Figure 4.2. The OPUS VII data defines the asymmetric structure with one end support station (ESS), two support stations (SS), and thirty demand

generating stations (DGS). Figure 4.3 represents the OPUS organizational structure. OPUS defines the C (Depot) level

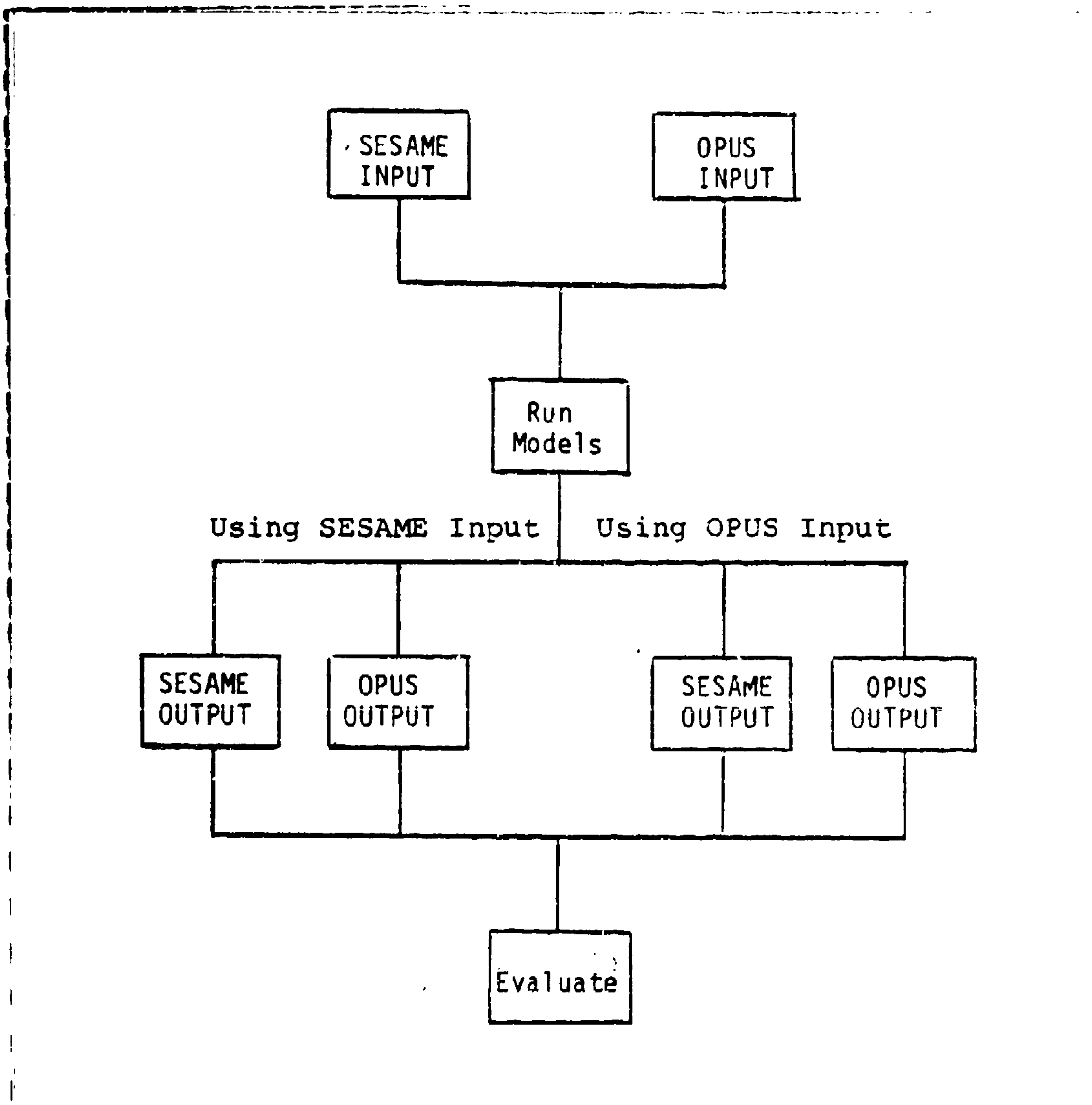


Figure 4.1 Numerical Test Problem.

as an ESS, B and A (Intermediate level) as SS, and CU (Organizational level) as the DGS. A represents the supply and maintenance capability and CU represents the combat user

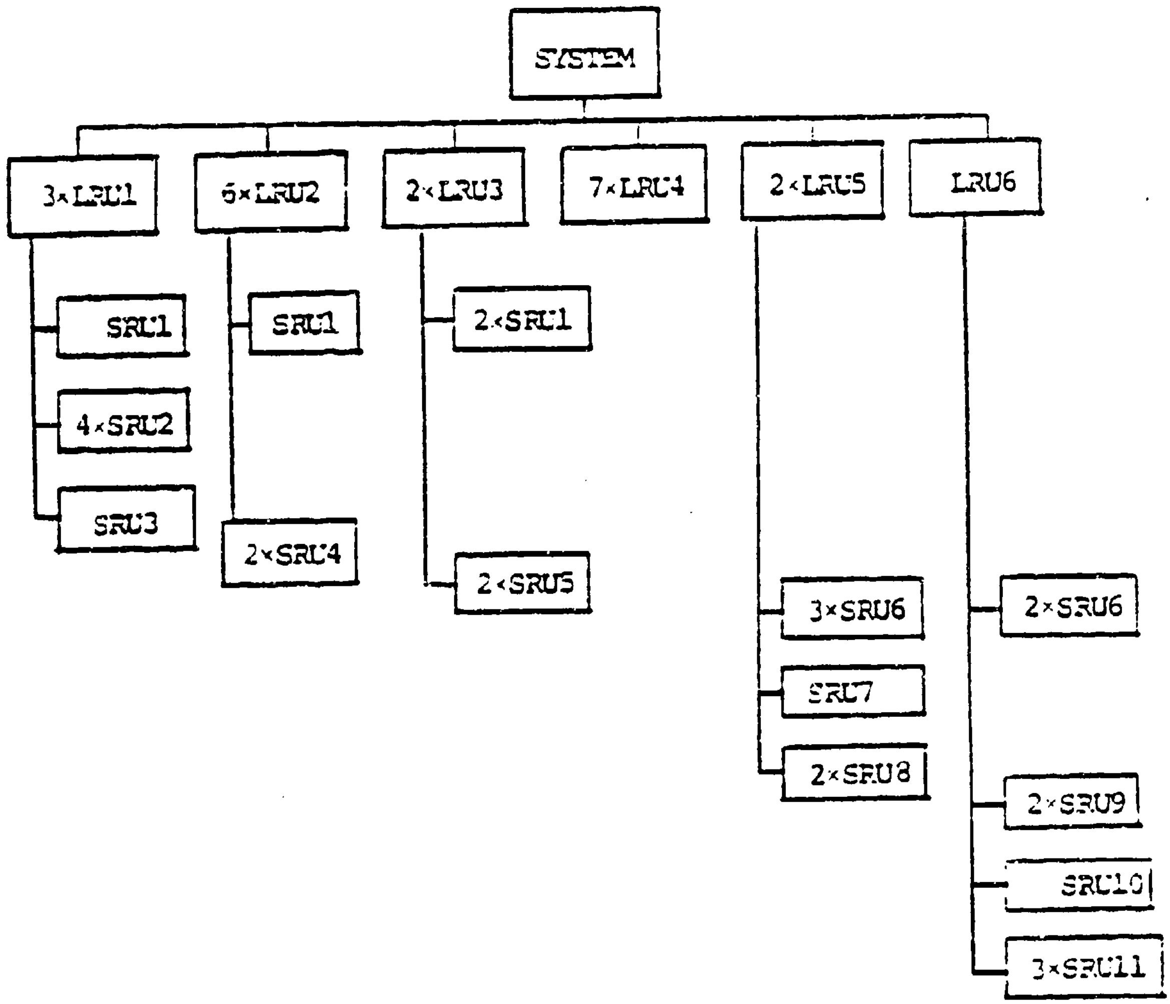


Figure 4.2 OPUS System Breakdown.

located at that echelon. Turnaround times are given for the ESS, SS and DGS levels. The DGS level reflects time required to get the part to the CU from the C SS.

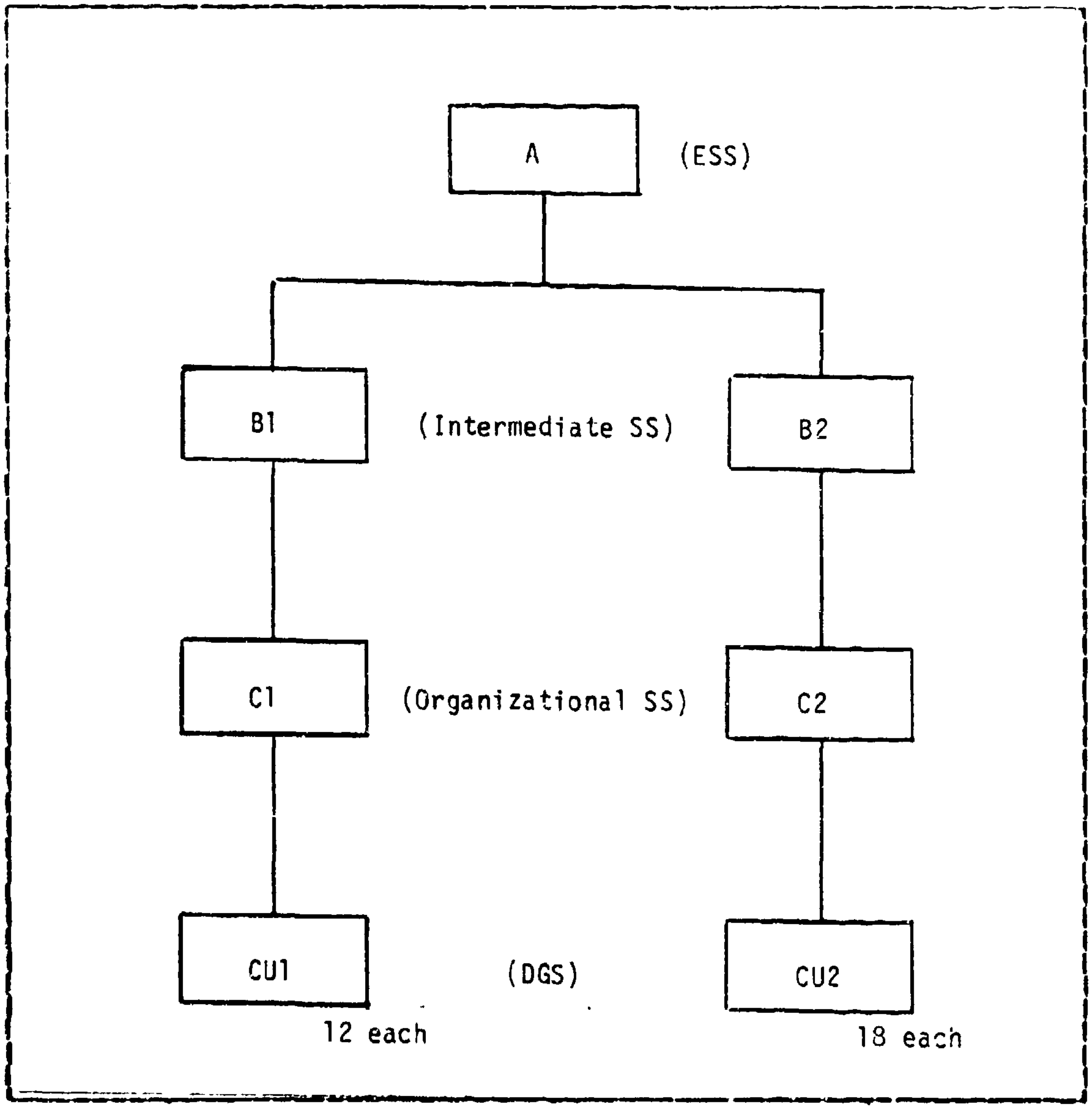


Figure 4.3 OPUS Organizational Structure.

C. SESAME DATA

The SESAME data were derived from test sample data received from the Army Inventory Research Office used to validate the SESAME model. The SESAME model was modified because the SESAME model uses only LRU's in determining A

while the OPUS model uses LRU's and SRU's in determining A . The structure of the SESAME test system is therefore only

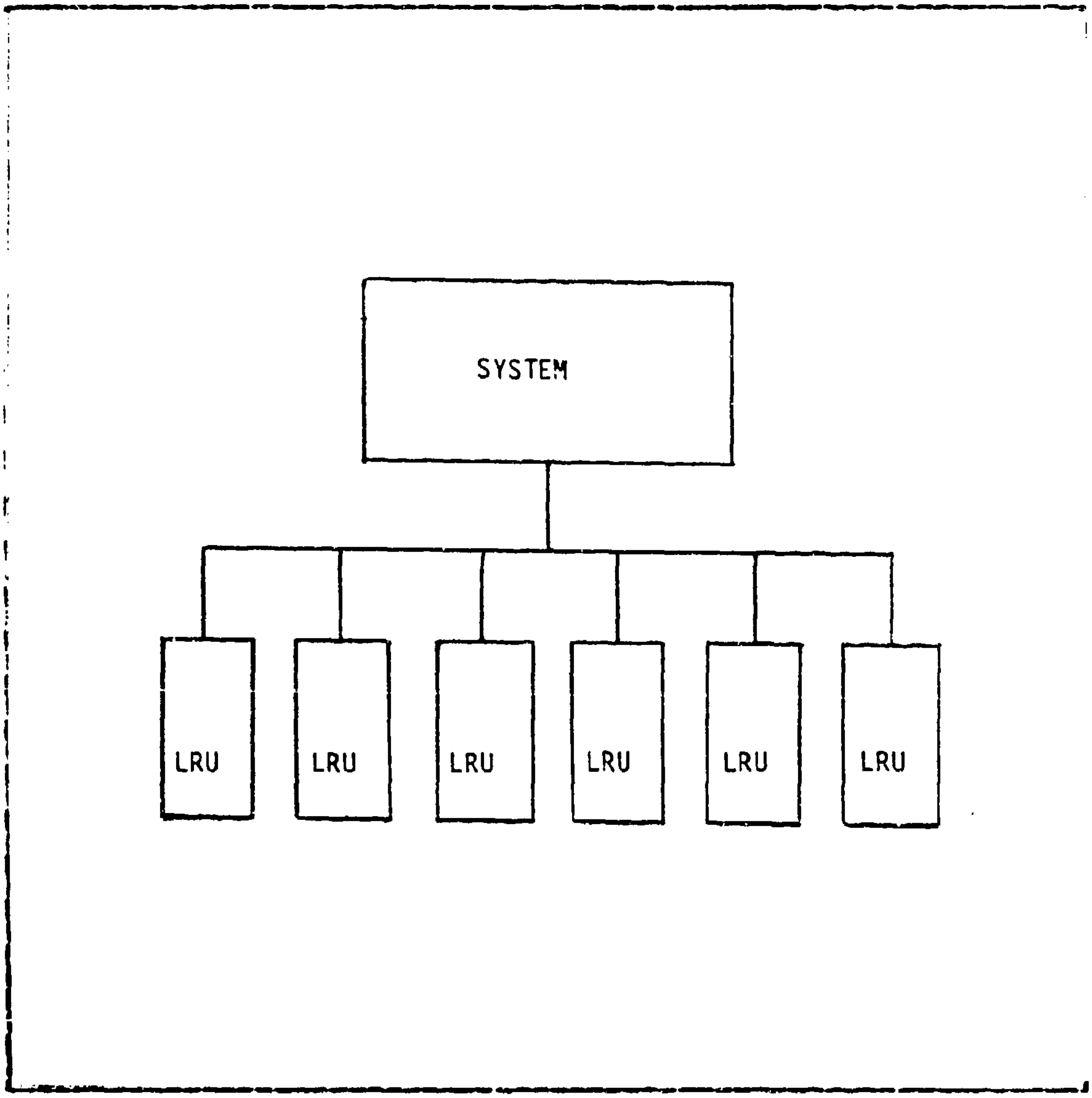


Figure 4.4 SESAME System Structure.

LRU's (Figure 4.4). SESAME uses SRU's to determine total system cost when the item is essential to the operation of the system. By using Essentiality/ Fault Isolation Module

codes (ESS/FIM code), the SESAME model determines whether to stock an item. If a part is essential, it is always stocked. If a part is non-essential, it is treated as a non-LRU even if it is an LRU. As a non-LRU, the item has no effect upon determining the total system operational availability. Similarly, if an item is denoted a Fault Isolation Module (FIM), it requires removal to determine failure. Items designated FIM are required to be stocked at least once at each echelon where the item can be removed and replaced. An item designated FIM can be a non-LRU item. A part can be designated FIM when it is an SRU if it is determined that the part must be removed in order to determine its status.

The SESAME organizational structure consists of one general support (GS), two direct support (DS), and thirty organizational (ORG) units (Figure 4.5).

D. INPUT DATA COMPARISON BETWEEN SESAME AND OPUS

Several problems exist in comparing OPUS input data to SESAME input data. SESAME does not handle multiple requirements for the same LRU in a system. Therefore, when OPUS inputs a requirement for three of the same LRU's in its system, SESAME will only input a requirement for one. To compensate for this, the failure factor in the SESAME model is multiplied by the number of items required by the system.

OPUS defines failure rate as the number of failures per million operating hours. SESAME uses a Failure Factor (FF) which is the number of peacetime removals of the part expected per hundred end items per year under specified usage and environmental conditions. With regard to this, SESAME also defines wartime versus peacetime usage and the different deployment areas (e.g. Europe, CONUS) where the part may be employed. Assuming Operating Hours per Day (OPHD) equals twenty four hours we can determine

OPUS (MTBF) x (24 hr/day) x (365 day/year) x (100 items) = SESAME FF (4-1)

where

MTBF = number of failures/1000000 Hours

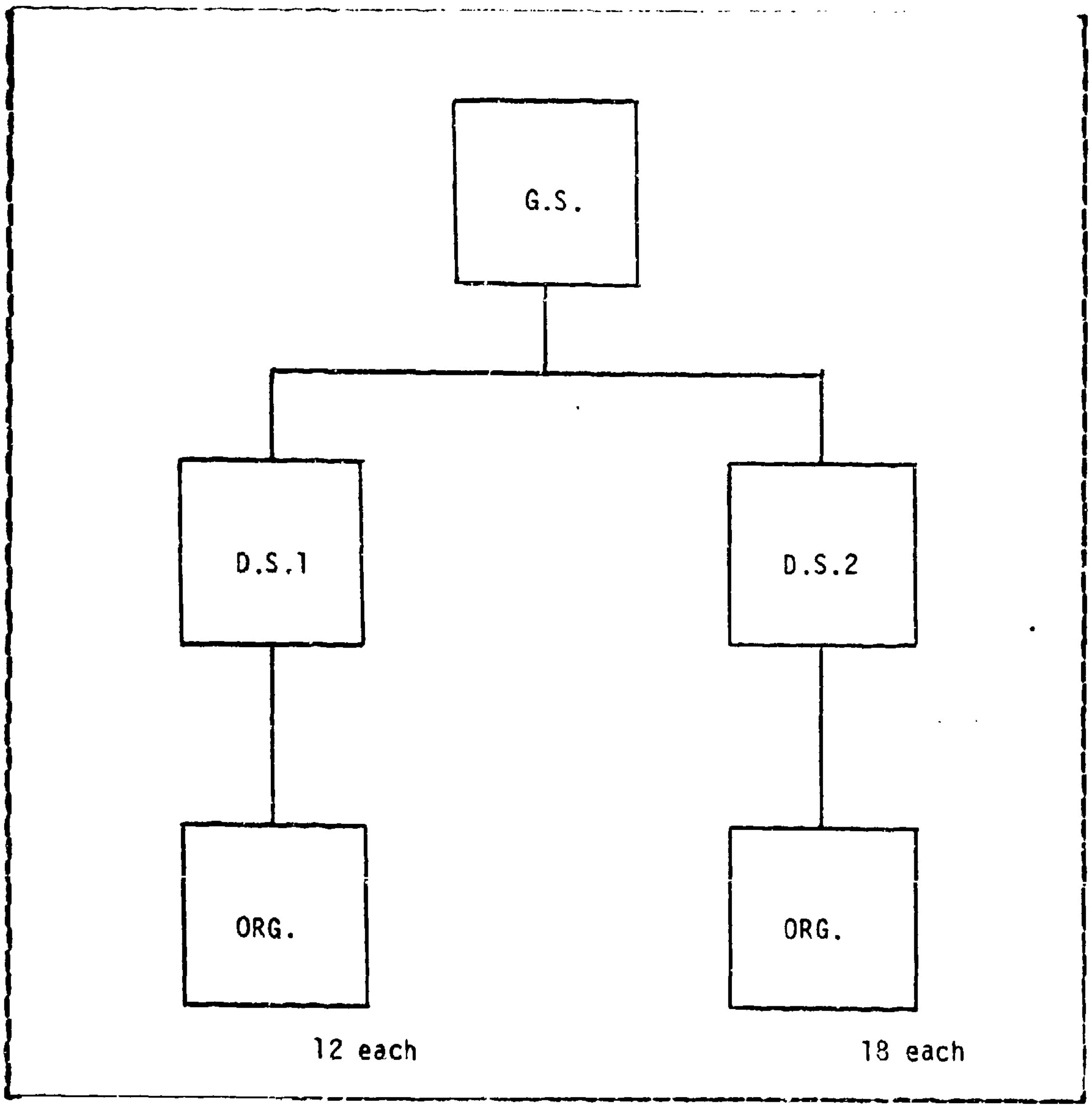


Figure 4.5 SESAME Organizational Structure.

SESAME requires Mean-Time-To-Repair as a control parameter in its optimizing algorithm. OPUS does not explicitly define an MTTR. To obtain a value of MTTR for SESAME, OPUS values were used to determine MTTR as follows:

OPUS MTTR= (FIM) + Time to Replace Part (TTRP) (4-2)

Upper and lower bounds are delineated by SESAME in terms of availability, AVMIN and AVMAX. OPUS determines its boundaries in terms of cost, CMIN and CMAX. Since these figures are related functions in both algorithms, setting boundaries can be accomplished and evaluated by manipulating one to obtain the other. For example, in SESAME, the target control parameter can be used to search for a specific cost or availability level. In OPUS, a combination of MOE's and CMAX can be used to obtain similar results.

The time necessary to restock an item from the next higher echelon is described as Order Ship Time (OST) in the SESAME model. This OST is broken down by organizational echelons. OPUS uses Transportation Time Return Trip (TRPT) and Transportation Return Trip (TNPYR) where each different support station may have a different return trip time. The difference between TNPYR and TRPT is that they represent the transportation times at different echelons. OPUS views each time independently, while SESAME treats them as the same at each echelon. The test problems were run using uniform return trip times for the OPUS suppport stations. An important factor to note is that SESAME does not include transportation time of an LRU to the next higher echelon if the LRU cannot be replaced at the present echelon. This is important because that time is not considered in determining MLDT.

SESAME defines its Repair Cycle Times (REPCYC) in terms of days necessary to ship the part to the repair facility plus the days needed to repair the item. SESAME denotes this

time at each organizational level. OPUS does not define a value similar to REPCYC, but a value can be derived as follows,

$$\text{OPUS Repair Cycle} = \text{TRPT} + \text{Admin Delay Time(ADT)} + \text{FIT} + \text{TTRP} \quad (4-3)$$

It is important to note that, REPCYC in SESAME does not include the time it takes to return a functional part back to the user.

E. VALUES UNIQUE TO EACH MODEL

1. SESAME Values

SESAME uses several values that are not considered by OPUS. These values have an effect upon the computation performed by the SESAME model and are discussed below:

a. Replacement/Maintenance Task Distribution (RTD/MTD)

SESAME requires inputs which define the percentage of total removals of an item at each level (RTD). These percentages across all echelons must sum to one hundred percent. Similarly, the MTD is the percentage of total items that are removed for repair at each level. The sum of these percentages plus the washout rate (REPR) must equal one hundred percent.

b. CURPAR

CURPAR is the estimated penalty cost associated with downtime. To represent minimum stockage, a CURPAR of .01 was used. A CURPAR of .01 represents a penalty cost for system downtime.

c. WHOFIL/CONDEL

WHOFIL is the wholesale stock availability, while CONDEL is the conditional delay time (the average time required for a major subordinate command to satisfy a requisition for an out-of-stock item). Both WHOFIL and CONDEL are set to default values as they have no effect on initial retail stockage in the standard initial provisioning (SIP) mode.

d. Unserviceable Return Rate (URR)

URR is an estimate of the ratio of unserviceable returns to the wholesale level to the total demands on the wholesale level. This value was set to zero (although typical values would probably range from .02 to .15) to make SESAME compatible with OPUS.

2. <u>OPUS Values</u>

OPUS defines several input values that are not considered by SESAME. These values affect system capabilities and are listed below:

a. System Breakdown Values

These inputs are listed together as they refer to the description of LRU's and SRU's in the system design. As SESAME does not use a complicated system design, a very simple test set from SESAME was used for OPUS. This test set consisted solely of LRU's with no multiplicity of parts. This was performed only for the SESAME test problem using original SESAME data.

b. Number of Different Systems (NYMAX)

OPUS has the ability to handle more than one system at a time. This parameter defines the numbers of systems and the requirements for defining those systems organizations. In running the problem, only one system was used, since SESAME can handle only one system at a time.

c. Probability that a station is supported by another (PNYPR)

This factor allow OPUS to cross level requisitions from higher echelons based upon the probability a DGS is supported by different SS as is shown in Figure 3.3. This probability is known as PNYPR.

F. RUNNING THE MODELS

The learning time required to become familiar with the operation of each model differed greatly. This is due in part to the fact that access to persons knowledgeable with SESAME was somewhat easier than access to persons knowledgeable with OPUS. The SESAME user manual was easier to read and comprehend than the OPUS user manual. SESAME ran in an interactive mode, therefore it took less calendar time to execute than OPUS in its batch mode. Calendar time is the time from job submission to receipt of model output. There is, however, an interactive version of OPUS. SESAME and OPUS both are sensitive to the input data, but it appeared that more problems were encountered entering and understanding the applications of the OPUS model. This was in part due to the lack of explanation of some terms in the OPUS user manual and the greater flexibility provided by the OPUS model.

G. SUMMARY

Both the OPUS and the SESAME models optimize spare stockage with regard to cost and operational availability. The design of the models causes different decisions to be made by the user when he uses these models. OPUS allows the user to determine the system structure and declare different repair policies at different echelons. SESAME allows more input to be made in terms of possible delay-causing factors, such as wholesale stockage. The SESAME model can search for a user specified cost or operational availability; OPUS lists the costs and availability based upon a generation of points from its C-E curve for other specified MOE's (waiting time, risk of shortage, probability of mission success).

V. EVALUATION OF THE TEST PROBLEMS

A. INTRODUCTION

The purpose of this chapter is to compare the outputs of the two models. A comparison of the outputs would manifest differences caused by the optimization algorithms used by each model. By varying specific parameters (e.g. MTBF, MTTR and turnaround time), the sensitivity of each model to the varied parameters could be explored.

1. Assumptions

In comparing the two models, it was necessary to construct the values of some of the model parameters from other parameters used in the models. For example, neither SESAME nor OPUS define a value for MTTR. In order to construct this parameter, the SESAME value REPCYC and the sum of the OPUS values Fault Isolation Time and Time to Repair Part were used. Similarly, for MTBF the SESAME failure factor and the OPUS failure rate were used, and for turnaround time the SESAME Order Ship Time and OPUS turnaround times were used.

B. DIFFERENCES IN THE INPUTS

1. Software Limitations

In conducting the comparison, certain problems arose because of the assumptions made and because of software limitations that existed within the models.

The problems caused by the software in the SESAME model were encountered when evaluating the OST and REPCYC. OPUS is limited to a maximum number of 500 different LRU's

and SRU's. This, however, did not affect the execution of the problem.

a. REPCYC Value

In SESAME, the REPCYC value is rounded off to an integer value by the software. For example, an input value of 0.5 is returned as an output value of zero. This rounded value will lead to inaccuracies in the stockage of spare parts because the REPCYC is used in the determination of the pipeline at a stockage point.

b. OST Value

The OST value is represented by SESAME in terms of days. The software used by SESAME allows for the input of integer values only. The transformation of hours to days caused the creation of values that were rounded off by the SESAME model. The use of integer values limits the lower value of the OST to one day and bounds the upper limit to 99 days. These value limits may be reasonable but exact values would be preferable in the computations of stockage levels. Since OST is also used in thhe determination of the pipeline quantities the use of integer values will cause an inexact answer to be rendered.

2. Differences in Output

a. Differences Caused by Assumptions

Several problems were found in trying to compare the outputs of the two models. The comparison of the failure rates produced the best results in terms of total cost comparisons and stockage.

The comparisons of MTTR and turnaround time were hampered by differences in model software and value definition. For example, in determining the MTTR of SESAME,

REPCYC does not include the time necessary to return the part to the user. In creating the OPUS value of MTTR, this meant taking only half of the turnaround time for the part.

The other problem in using MTTR is the fact that OPUS does not define a system MTTR. The value of MTTR can be determined at each echelon but a system value is not determined. A value for MTTR is inserted as a control parameter in SESAME and it is used to determine the operational availability of the system. This operational availability forms an upper bound for the optimization calculation. Therefore, an incorrect input value of MTTR will raise or lower the level of availability that the SESAME model can attain.

C. PROBLEMS CAUSED BY THE ALGORITHMS

1. Differences in the SESAME Algorithm

The SESAME model has several different components that are necessary for its determination of availability in its two operational modes of budget and availability. OPUS uses only one method of optimization.

a. Different Procedures used by SESAME.

SESAME uses the extrapolation procedure and stockage list method to forecast the budget. The extrapolation procedure is used when only partial data are available. The stockage list budget method is used when more information is available about the parts. In the comparison used, the stockage list budget method was used.

b. Different Stockage Criterion used by SESAME.

The stockage of parts within SESAME is broken into wholesale and retail levels, OPUS does not make this distinction. This becomes important if the number of

washouts per end item per year is very large. The washouts of an end item are the number of items that cannot be repaired economically. OPUS does not use washouts in its determination of stockage.

c. Differences in Measures of Effectiveness

The differences in the stockage policy used by SESAME and OPUS made it extremely difficult to compare the models. The comparison of operational availability does not take into account the different levels at which each model requires stockage. For example, OPUS may provide a higher operational availability but at the same time have a high risk of shortage at the Demand Generating Station level. The pipeline stockage used by SESAME allows it to stock at the echelon where the repair is expected to occur. Therefore it can stock at lower levels first. In order for OPUS to reach the same level of repair, OPUS would have to stock additional parts at the organizational level.

D. DIFFERENCES IN OUTPUT

The SESAME model allocates spares in the standard initial provisioning mode according to pipeline quantity rounded to an integer. The stockage value determined by SESAME reflects the values used to determine the pipeline. SESAME requires the user to input the percentage of demand to be repaired at a stockpoint. The pipeline value of stockage therefore reflects the echelon where the demand will be replaced. For example, if all repairs for a given part are to be at the organizational level, then the pipeline will not stock parts at a higher level. An exception to this is when the pipeline is less than one but the expected annual demands exceed the Retail Stock Criterion (6 per year in this case). In this case SESAME

uses the value one regardless of the pipeline quantity. OPUS stocks on the basis of the spare which gives the highest Cost-Effectiveness at the highest echelon and then continues stocking according to the next highest ranking. In this sense, OPUS stocks from top down without determining what the echelon repair breakdown will be.

1. Printed Output

SESAME returns all input data to the user. By selecting a parameter called TARGET, SESAME can search for availability or total cost as the optimizing factor. When SESAME is run in the SIP mode, a detailed printout shows all values which satisify the target. A sample of this printout is given in Appendix D. The SESAME printout lists all spares and quantities for each demand generating organization. It further compiles a listing of the stockage cost for these spares by echelon.

OPUS lists all its parts and stockage in a more concise manner. It is easier to read but does not include the total cost of stockage that the SESAME model provides. The OPUS model provides all the points it uses to create its cost-effectiveness curve. This causes the printout of the OPUS model to take more time. The advantage of this is that the user can examine various points of the curve with regard to the various OPUS MOE's without having to rerun the model. To conduct a similar task with SESAME would require multiple runs using different parameters. A sample of the OPUS printout is included as Appendix C.

E. COMPARISON OF THE OUTPUT OF THE MODELS

Each model was run using its own input data and the input data of the other model. A total of four outputs were produced and compared. For all comparisons, a target

availability of 0.975 was used. If this value was not reached, the next value higher was used as the reference point. For SESAME, when the target parameter was set, the model would search until the stockage allocation reached the target availability or the Standard Initial Provisioning stockage. Tables I and II give the OPUS and SESAME stockage allocation for OPUS input.

TABLE I

OPUS Stockage Using OPUS Input Data

SPARE	TOTAL	INVESTMENT	C	B1	B2	A1	A2
LRU 1	34	557600	0	2	2	1	1
LRU 2	66	1656600	0	3	3	2	2
LRU 3	34	754800	0	2	2	1	1
LRU 4	64	1036800	0	2	2	2	2
LRU 5	34	1934600	0	2	2	1	1
LRU 6	66	3649800	1	2	3	2	2
SRU 1	9	51300	7	1	1	0	0
SRU 2	5	10000	3	1	1	0	0
SRU 3	3	8100	1	1	1	0	0
SRU 4	10	97000	7	1	2	0	0
SRU 5	4	21600	2	1	1	0	0
SRU 6	8	90400	5	1	2	0	0
SRU 7	1	5600	1	0	0	0	C
SRU 8	3	26100	1	1	1	0	0
SRU 9	4	15600	2	1	1	0	0
SRU 10	1	4200	1	0	0	0	0
SRU 11	6	41400	4	1	1	0	0
TOTAL COST		9961500					

The difference in stockage between SESAME and OPUS can be recognized when comparing the respective stockage outputs. OPUS stocks at different levels depending upon turnaround time and repair time. The SESAME output using OPUS data stocks at the lower echelons in more cases as a result of the assumed levels of repair that were used to run the SESAME model. The maintenance/repair task distribution entered in the SESAME model (Appendix A) requires that

TABLE II

SESAME Stockage Output Using OPUS Input Data

SPARE	TOTAL	INVESTMENT	C	B1	B2	A1	A2
LRU 1	32	524800	0	1	1	12	18
LRU 2	36	903600	0	2	4	12	18
LRU 3	32	710400	0	1	1	12	18
LRU 4	32	518400	0	1	1	12	18
LRU 5	46	2741600	13	1	2	12	18
LRU 6	54	2986200	19	2	3	12	18
SRU 1	2	11400	2	0	0	0	0
SRU 2	0	0	0	0	0	0	0
SRU 3	0	0	0	0	0	0	0
SRU 4	6	56200	4	1	1	0	0
SRU 5	0	0	0	0	0	0	0
SRU 6	5	56500	3	1	1	0	0
SRU 7	0	0	0	0	0	0	0
SRU 8	2	17400	2	0	0	0	0
SRU 9	1	3900	1	0	0	0	0
SRU 10	0	0	0	0	0	0	0
SRU 11	2	13800	2	0	1	0	0
TOTAL COST		8546200					

spares be repaired at the lower levels. The ability to replace LRU's with SRU's enables OPUS to have a smaller stockage of LRU's at the Demand Generating Station. Opus stocks more LRU's and SRU's cumulatively than SESAME. Although SESAME does not use SRU's in its availability computation, SESAME will stock a number of SRU's based upon

TABLE III

OPUS Stockage Output Using SESAME Input Data

SPARE	TOTAL	INVESTMENT	C	B1	B2	A1	A2
LRU 1	28	719600	0	0	0	1	1
LRU 2	28	294000	0	0	0	1	1
LRU 3	28	266000	0	0	0	1	1
LRU 4	28	140000	0	0	0	1	1
LRU 5	28	263200	0	0	0	1	1
LRU 6	28	484400	0	0	0	1	1
TOTAL COST		2167200					

the Retail Stockage Criterion.

Tables III and IV represent the differences that occur

TABLE IV

SESAME Stockage Output Using SESAME Input Data

SPARE	TOTAL	INVESTMENT	C	B1	B2	A1	A2
LRU 1	12	308400	2	5	5	0	0
LRU 2	5	52500	1	2	2	0	0
LRU 3	14	133000	2	6	6	0	0
LRU 4	45	225000	1	13	13	14	14
LRU 5	23	216200	21	1	1	0	0
LRU 6	2	34600	2	0	0	0	0
TOTAL COST		969700					

when both models are run using the SESAME set of input data.

In Table III the stockage determined by OPUS is primarily at the lower echelons. This stockage is caused by the high Order Ship Time between levels used by the SESAME model. The high turnaround time between the GS and lower echelons require that parts be stocked at the lower echelons if the availability target is to be met. Table IV reflects the impact of the Maintenance/Repair Task Distribution on the SESAME stockage levels. When the stockage levels are low it reflects a low Maintenance/Repair Task Distribution (MTD/RTD) at that level. When MTD/RTD is high at a level, the stockage at that level will be high.

F. COMPARISON OF OPERATIONAL AVAILABILITY BETWEEN SESAME AND OPUS

Table V represents the target operational availabilities achieved by each model with each different set of input data. It should be noted that although OPUS achieves a higher operational availability at a lower cost, it is accompanied by a high risk of shortage. Data set 1

represents the OPUS original input data set. Data set 2

TABLE V

SESAME and OPUS Operational Availability

MODEL	INPUT DATA	A	TOTAL COST
SESAME	Data Set 1	.945287	8553100
SESAME	Data Set 2	.930158	1019700
OPUS	Data Set 1	.97691[1]	1807600
OPUS	Data Set 2	.99309[2]	0

NOTE 1: This point has achieved a higher availability than the SESAME model. The risk of shortage at this point is 1.0. At a total cost of 9158800, an availability of .99889 was achieved with a risk of shortage of .00196515.

NOTE 2: This point reflects the excellent ability of the repair facilities to repair spares. The risk of shortage is 1.0. At a total cost level of 1153600 an availability of .99773 was achieved with a relatively high risk of shortage of .19966024.

represents the original SESAME unput data set.

G. COMPARISON OF MODELS VARYING PARAMETERS

SESAME and OPUS were evaluated by comparing the output of each model while varying MTBF, MTTR and Turnaround Time.

1. Comparison of SESAME and OPUS when varying MTBF

To compare OPUS and SESAME, the failure factor and failure rate of each model were varied. The original parameter values were divided by two, multiplied by two, and multiplied by four. In all, this led to 16 sets of output data when including the original data set. Table VI below depicts SESOPUS values which are the total cost of the SESAME model using OPUS input, SESAME are SESAME cost using

SESAME data, OPUS are OPUS cost using OPUS data, and OPUSSES are OPUS cost using SESAME data.

TABLE VI

Effects Upon Total Cost When Varying Failure Rates

MTBF VALUE	SESOPUS	SESAME	OPUS	OPUSSES
MTBF/2	8569200	5066300	9953900	2573200
MTBF	7628600	3206800	9578300	2307200
2MTBF	6498900	1092100	9961500	2167200
4MTBF	6376400	487900	9761900	2167200

TARGET AVAILABILITY 0.975

By varying failure rate, we see that the SESAME model produces more predictable trends in total cost than the OPUS model. The SESAME2 output using SESAME input data almost reflects a linear increase in total cost. The OPUS model using OPUS input reacted in a different manner, increasing when the rates were divided and then again as the rates were quadrupled. This occurence is created by the OPUS algorithm which selects the spare which gives the best C-E curve. Changes in the failure rate for OPUS cause changes which are not as large as those created by SESAME, nor is there an observable trend.

2. Comparison of SESAME and OPUS when Varying MTTR

Table VII illustrates the effect of varying MTTR in both the SESAME and OPUS models.

TABLE VII

Effects Upon Total Cost When Varying MTTR

MTTR VALUE	SESOPUS	SESAME	OPUS	OPUSSES
MTTR/2	6443600	747300	9960300	2167200
MTTR	6498900	1092100	9961500	2167200
2MTTR	11083400	1731100	9731500	2307200
4MTTR	16287000	3124100	9793100	2573200

TARGET AVAILABILITY 0.975

The results of changes in the values of MTTR indicate that the SESAME model is more sensitive to changes in the values related to repair. In both the SESAME and SESAME2 outputs the changes are more dramatic than in either of the OPUS outputs. This difference implies that the Repair Cycle Time used to estimate the MTTR for SESAME has more impact in its algorithm than the assumed value for MTTR used for the OPUS model. In performing the comparison, one difficulty was the determination of the system value of MTTR for OPUS. The value assumed for the OPUS system MTTR may not accurately reflect the actual system MTTR.

3. Comparison of SESAME and OPUS when Varying Turnaround Time

TABLE VIII indicates variations in output when varying turnaround time.

The comparison of turnaround times caused several problems because of he limitations of the SESAME software. The Order Ship Time used by the SESAME model quickly reached its upper limit of 99 days therefore preventing the use of any greater value. The SESAME problem therefore had no

TABLE VIII

Effects Upon Total Cost When Varying Turnaround Time

TAT VALUE	SESOPUS	SESAME	OPUS	OPUSSES
TAT/2	8553100	3056200	9998200	2167200
TAT	6498900	1092100	9961500	2167200
2 TAT	8553100	3195400	9089600	2167200
4 TAT	8553100	3195400	9001800	2167200

TARGET AVAILABILITY 0.975

change in Order Ship Time for the 2 TAT and 4 TAT levels. The OPUS problem was able to handle the changes in the TAT. The OPUS output indicates the sensitivity of the OPUS model to turnaround time.

H. SUMMARY

The comparison of model outputs reflects the differences in the nature of the algorithms used by each model. The SESAME model stocks as a function of the pipeline function while OPUS stocks with respect to repair and turnaround time. The SESAME model tells us how much to stock at each echelon if we know how much repair will occur at that level. The OPUS model tells us where to stock parts based upon how well the maintenance facilities (function of repair time and turnaround time) function. In general, SESAME appears to stock for Standard Initial Provisioning at a lower total cost than OPUS.

VI. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

Based upon the model analysis and the test problems, the following are concluded:

a) When budget considerations impact upon the fielding of spares, the SESAME model should be used.

b) When there is limited information available about the level at which repairs are to be made, the OPUS model should be used. SESAME is a useful model for determining optimization when repair requirements at each level are defined.

c) In both models, the quantity and optimum allocation of spares are sensitive to the value of MTBF.

d) The effect of time elements in the repair cycle have a greater effect for the lower levels of the support organization. This is shown by the greater stockage at lower echelons when turnaround time is very high at the upper echelon units.

e) OPUS VII has several MOE's and therefore allows more detailed analysis in terms of the optimization of spares provisioning.

f) SESAME must be run once for each system being studied.

g) SESAME must be run several times to determine optimal stockage when the required repair level for parts is not specified.

h) SESAME does not use a system structure which allows the stockage of an SRU when it fails.

i) OPUS does not differentiate between different types of SRU's, for example, Fault Isolation Modules. Fault Isolation Modules are mandatory stockage within the SESAME model.

j) OPUS allows units to be supported by more than one higher echelon unit through the use of the parameter probability of being supported by the next higher unit (PNYPR).

k) OPUS allows for selection of stockage points by providing selected points and MOE's along the C-E curve.

l) SESAME provides a TARGET function which allows the user to quickly determine if a specified Operational Availability is possible and at what cost.

m) SESAME handles Wholesale and Retail level stockage requirements in that it defines wholesale repair and depot washout rates while OPUS does not handle wholesale level stockage.

n) SESAME addresses the problem of parts that are uneconomicly repairable. OPUS does not define depot level washouts nor the unserviceable repair rate.

o) SESAME uses a Retail Stockage Criterion which affects the minimum stockage.

B. RECOMMENDATIONS

As a result of the analysis and the test problems the following recommendations are made:

a) SESAME should modify REPCYC to handle total turnaround time.

b) Software in SESAME should be modified to allow for actual values (in hours) for Order Ship Time.

c) Software in SESAME should be reviewed to eliminate the effect of round-off errors.

d) The SESAME algorithm needs to address the fact that LRU's that fail as a result of component SRU's may be repaired by repairing the SRU.

e) If possible, additional MOE's should be investigated when utilizing the SESAME model.

f) The output of the SESAME model should

be simplified.

g) OPUS should introduce MTTR values for the system, LRU's and SRU's.

h) OPUS should use a target parameter which will provide a specific answer based upon specified boundaries. This will save the user searching the output for a specific answer.

i) The OPUS input data format needs to be simplified or restructured to make it more user efficient.

j) OPUS needs to print the number of spares that are not repairable and have to be replaced by stockage.

k) SESAME needs to have more station values rather than system values, especially in the asymmetric structure. For example, the OST is the same for all stations in the structure.

l) SESAME needs to look at the asymmetric structure and the impact of RTD/MTD values on the asymmetric structure. The asymmetric structure may cause these values to be non-uniform for all stations at a given echelon.

APPENDIX A

SESAME MODEL INPUT DATA

This appendix shows two examples of input data into the SESAME model. The following is an explanation of the format of the two data sets. The first data set will be used as an example.

1) The first line starting with 6V represents the End Item/Weapon System Data (Peace). Following is an explanation of each entry:

6	represents the Retail Stockage Criterion,
V	represents the Supply Structure Option (in this case vertical),
30 2 1	represents number of units at each echelon in this case 30 Organizational, 2 Direct Support, 1 General Support,
010360	represents OST at each eachelon, 1 day at ORG., 3 at DS, 60 at GS
30	represents cumulative end item density,
1 14 30	represents operational units of program, (not used when Asymmetric System Mode ASM=2),
1.	unserviceable return rate,
30 30 30	operating level days at each echelon, ORG,DS,GS,
0	beginning density,
2	asymmetric support option code,
C	geographic area selector (C=Conus).

2) The next line is 3 CGS 1 510 1 1. This is the beginning of the asymmetric support structure data. This data ends with the 1 A201 17 18 18. 3 represents the echelon number.

CGS1 is the unit identification.

510 is the number of end items supported.

1 is the number of units of the type identified in column two that are in the system by budget allocation.

1 is the number of units supported.

3) The next 17 lines represents the part data. The first line of this data begins with 000000001. The last line of this data begins with 000000111. The first six lines are the LRU's, the next eleven lines are the SRU's. Using the SRU data item

000000101 is the part number.

18.1 is the failure factor.

0 is the replacement or washout rate.

5700.0 is the unit price.

22200.0 (see line with part number 000000101) is the unit price of the next higher assembly.

80 10 10 represents the replacement task distribution at each level, ORG,DS,GS, respectively.

801010 represents the maintenance task distribution at each level, ORG,DS,GS, respectively. The values .55.167. represents the repair cycle time in days.

(.56.069.) is the ORG REPCYC .5 days for ORG, DS is 6.0, and

GS is 69.

3 represents the essentiality code. (1,5,7 are essential and 2,3,4,6,8,9 are non-essential).

N represents the LRU indicator (L is LRU, N is non-LRU).

APPENDIX A   SESAME MODEL USING OPUS INPUT DATA

FILE: SESAME   DATA   A   NAVAL PCSTGRADUATE SCHOOL

```
6V     30 2 1  010360                           30   1  14  30  1.    30 30 30   0 2  C
 3  CGS1    510     1     1
 2  BDS1    204     1     1
 1  A101     17    12    12
 2  BDS2    306     1     1
 1  A201     17    18    18

000000001   94.6 0    16400.0              80 20   0        8020 0     .55.167.       1L
C00000002  275.1 0    25100.0              70 30   0        703000     .55.167.       1L
000000003  111.0 0    22200.0              70 30   0        7030 0     .55.167.       1L
000000004  126.0 0    16200.0              80 20  00        8020 0     .55.167.       1L
000000005  136.7 0    59600.0              60 30  10        603010     .55.167.       1L
000000006  206.7 0    55300.0              60 30  10        603010     .55.167.       1L
000000101   18.1 0     5700.0     22200.0  80 10  10        801010     .56.069.       3N
C0000C102    5.3 0     2000.0     16400.0  80 10  10        801010     .56.069.       3N
000000103    1.4 0     2700.0     16400.0  80 10  10        801010     .56.069.       3N
C00000104   36.8 0     9700.0     25100.0  80 10  10        801010     .56.069.       3N
000000105    9.6 0     5400.0     22200.0  80 10  10        801010     .56.069.       3N
C00000106   29.8 0    11300.0     59600.0  80 10  10        801010     .56.069.       3N
000000107    8.8 0     5600.0     59600.0  80 10  10        801010     .56.069.       3N
CC0C00108   19.3 0     8700.0     59600.0  80 10  10        801010     .56.069.       3N
000000109   14.9 0     3900.0     55300.0  80 10  10        801010     .56.069.       3N
C00000110   10.5 0     4200.0     55300.0  80 10  10        801010     .56.069.       3N
000000111   24.5 0     6900.0     55300.0  80 10  10        801010     .56.069.       3N
```

APPENDIX A   SESAME MODEL USING SESAME INPUT DATA

FILE: SESAME2 DATA   A   NAVAL PCSTGRADUATE SCHOOL

```
6V     28 2 1   010360                           28   1  14  28   1.12  30 30 30      2  C
 3  GSU1    168     1     1
 2  DSU1     84     1     1
 1  ORG1      6    14    14
 2  DSU2     84     1     1
 1  ORG2      6    14    14

ITEM1         71 7    25700.0          0100    0   0   0   0 093 0 0 0   1 30100   0   0 1L
ITEM2         22 7    10500.0          0   0100    0   0   0 093 0 0 0   1 30100   0   0 1L
ITEM3         81 7     9500.0          0   0100    0   0   0 093 0 0 0   1 30100   0   0 1L
ITEM4        181 0     5000.0          0100    0   0   0   0 099 0 0 0   1 30100   0   0 1L
ITEM5         47 7     9400.0          0100    0   0   0   0 0  093 0 0  1 30100   0   0 1L
ITEM6         67 7    17300.0          0100    0   0   0  093 0  0 0 0   1 30100   0   0 1L
```

APPENDIX B
OPUS MODEL INPUTS

The following are samples of OPUS input data sets used to run the OPUS model. Listed here are two data sets, one representing the original OPUS data, and one representing a SESAME data set. The following information will provide the reader with an understanding of each data input variable. The first set of data will be used as an example.

1) The first line is the title card. It names the run as example 2 dated 23 October 1983. The MOE used is Expected Waiting Time and the problem type is initial procurement.

2) The next line 0 0 0. 1.E +7 0 0 0 0 0 1. 0 is the problem card.

0 represents problem type in this instance 0 is the initial procurement of spares.

0 represents the MOE used in this case 0 is Expected Waiting Time.

0. 1.E+7 represent the minimum and maximum level of investment for this run.

0 is a default notation which means that the number of points selected for an internal C-E curve of the optimization process is 15 (this is optional).

0 represents the number of points to be selected for the final C-E curve, in this case 30 (this is optional).

0 represents the IOUTP which is the output printing control. In this instance the 0 means that no printing of points of the C-E curve will occur.

0 represents IPLOT, which is a plotting control. IPLOT set to 0 tells the program to plot all points, calculated by the program, from which internal and final C-E curves are plotted.

0 is the value for IPUNCH which tells the program not to use OPUS7W which is operated by punched cards.

1. is a value that is multiplied by the demand rate if the user determines the demand rate requires adjustment.

3) The next line has an 11. This 11 is the number of different SRU's that are present within the system.

4) The next block starting with SRU 1 and ending with SRU 11 is the SRU data block.

SRU 1 is the identification of the particular SRU.

5700 represents the unit price of the SRU.

20.7 is the failure rate of the SRU.

1. represents the application factor for that SRU.

If the system has no SRU's, then this block may be omitted.

5) The next line beginning with a 6 represents the number of different LRU's. The two 75's represent the length of the x and y axis of the plot.

6) The next block beginning with the value LRU 1 and ending with the line beginning with 6 (following line beginning with LRU 6), is the LRU data. The first LRU data set consists of two lines.

LRU 1 is the identification of the LRU.

16400. is the unit price of the LRU.

54.0 is the failure rate.

1. represents the application factor.

3 is the number of different SRU's within this LRU.

7) The next line describes the breakdown of the LRU into component SRU's. In this example, there is one type one SRU in this LRU, four type two SRU's, and one type three. This pattern may be continued for as many SRU's that may make up a specific LRU. This techniques is used for all the required LRU's.

8) The next line following the LRU block is the systems card. This is the number of different systems that are to be used in the computation. For this problem there is only one system.

9) The next line defines the system data.

SYSTEM 1 is the identification of the system.

1.0 represents the utilization rate per calendar hour of this system.

6 represents the number of different LRU's that make up this system.

10) The seven in the next line represents the number of different stations in the organizational structure.

11) The next block represents the organizational data.

1 represents NYSM, the number of stations of this type. Therefore, there is one C type station.

C is the identification of this type station.

0 represents NYPR or the number of the station that this station is supported by. In this case, this station is not supported by any higher station.

1 is the level identification parameter. This means that this unit is a first level unit. A unit with a 2 as a level identification parameter would mean that it is a second order unit.

1440 is the TRPT or the transportation time return trip for this station. This means that it takes 1440 hours for this unit to receive and return a part for repair.

11 represents the number of different SRU's to be stored by this unit.

720 is hours of administrative delay time.

6. is the fault isolation time for an SRU at this station.

168. is the time to replace the SRU at this level.

6 is the number of different LRU's stocked at this station.

720. is the administrative delay time for the LRU's.

6. is the fault isolation time of the LRU at this station.

48. is the time to replace the SRU of the LRU at this station.

12) The next line starts with a 0 which is the stock level of this station.

1 is the SRU type.

1 is the proportion to be stocked at this level. This format of stock level, SRU type, and proportion to be repaired is continued for all the SRU's stocked at this level. In this case, it is carried over to the next line and ends with

a 0 stock level, SRU type 11 repaired at 1.0. This format is similar for all data entered at different levels. The exceptions being that it is possible for a station to pass a supply request and not stock at that station. In this problem, stations B1 and B2 both serve as "dummy" stations and have a -11 in column for number of SRU's to be stocked. This indicates to the computer that none of the SRU's are to be stocked at these stations. Similarly, for stations A1 and A2 the -1, -2 for A1 and -1,-3 for A2 represent the fact that they are not the DGS at their level. They are supporting CU1 and CU2 which are the DGS at that level.

13) The line 24. 12. 1. 24. represents mission times for possible different missions at that station.

24 is the mission time (used in the optimization),

12. is mission time (used only in MOE calculation),

1. is the application factor.

24. is time between missions.

14) The next line is data about the station supporting this station.

2 represents the station level parameter which supports this station.

1. represents the probability that this station is supported by station 2.

24. is the transportation time return trip between this station and the supporting station.

15) The next line describes the LRU stockage at this level. It states that there is 0 stocked for each of six LRU's

which have 0. proportion of repair at this level. This last station CU1 and CU2 have the same format in their first line.

12 CU1 4 4 1. means that there are 12 type CU1 stations supported by station 4, with level parameter identification 4 and transportation time return trip this station of 1 hour.

```
EXAMPLE NO.2 102383    MCE=EXPECTED WAITING TIME PT=INIT PROC
     C      0          0.      1.E +7                 0     0     0     0     0    1.     0
    11
  SRU 1     5700.       20.7              1.
  SRU 2     2000.        6.0              1.
  SRU 3     27(0.        9.3              1.
  SRU 4     9700.        42.0             1.
  SRU 5     5400.       11.0              1.
  SRU 6     11300.       34.0             1.
  SRU 7     5600.       10.0              1.
  SRU 8     8700.       22.0              1.
  SRU 9     3900.       17.0              1.
  SRU10     4200.       12.0              1.
  SRU11     6900.       28.0              1.
     6          75    75
  LRU 1     16400.     54.0               1.     3
     1     1    2     4     3      1
  LRU 2     25100.     104.7              1.     2
     1     1    4     2
  LRU 3     22200.      63.4              1.     2
     1     2    5     2
  LRU 4     16200.      36.0              1.     0

  LRU 5     56900.     156.0              1.     3
     6     3    7     1     8      2
  LRU 6     55300.     236.0              1.     4
     6     2    9     2    10      1     11     3
     1
  SYSTEM 1                           1.0       6
     1     2     2     3     3     2      4    4     5     1     6     1
     7
  1 C      0     11440.    11 720.    6. 168.     6 720.    6.    40.
  0  1    1. 0   2    1. 0  3   1. 0  4   1. 0  5   1. 0  6   1. 0  7   1. 0  8   1.
  0  9    1. 0  10    1. 0 11   1.
  0  1    1. 0   2    1. 0  3   1. 0  4   1. 0  5   1. 0  6   1.
  1 B1    1      2   72.   -11                    6  84.    2.   24.
  0  1    1.0    2    1. 0  3   1. 0  4   1. 0  5   1. 0  6   1.
  1 B2    1      2   72.   -11  0.    0.    0.    6  84.    2.   24.
  0  1    1.0    2    1. 0  3   1. 0  4   1. 0  5   1. 0  6   1.
 12 A1   -1      3   -2.                          6
 24.       12.          1.         24.
  2   1. 24.
  0  10.    0   20.   0   30.    0  40.     0  50.    0  60.
 18 A2   -1      3   -3.                          6
```

FILE: OP10A   JOB   A   NAVAL PCSTGRADUATE SCHOOL

```
24.         12.         1.          24.
 3   1. 24.
 0  10.    1   20.     1   30.     C  40.     0  50.     0  60.
12C01     4      4   1.                                              1
 1   1    1.
18C02     5      4   1.                                              1
 1   1    1.
//
/*
```

```
EXAMPLE NO.2 102383    MOE=EXPECTED WAITING TIME PT=INIT PROC
  0     0              0.     1.E +7                          0      0      0    1.     0
  0
                 0.         .0                1.
  6            75     75
 LRU 1        25700.      81.1                1.
   C       0
 LRU 2       10500.      25.1                1.
   0       0
 LRU 3         9500.      92.5                1.
   0       0
 LRU 4         5000.      206.6               1.
   0       0
 LRU 5         9400.      53.7                1.
   0       0
 LRU 6       17300.       76.5                1.
   0       0
   1
 SYSTEM 1                                   1.0       6
   1      1      2      1      3      1          4      1      5      1      6      1
   7
 1C1       0       11440.                         168.0       6  936.   24.
 0    1   1.0  0   2   1.0  0   3   1.0  0   4    1.0  0   5   1.0  0   6    1.0
 1B1       1       2   72.                                    6   24.   12.
 0    1   1.0  0   2   1.0  0   3   1.0  0   4    1.0  0   5   1.0  0   6    1.0
 1B2       1       2   72.                                    6   24.   12.
 0    1   1.0  0   2   1.0  0   3   1.0  0   4    1.0  0   5   1.0  0   6    1.0
 14A1      2       3   24.                                    6    6.    6.
 0    1   1.0  0   2   1.0  0   3   1.0  0   4    1.0  0   5   1.0  0   6    1.0
 14A2      3       3   24.                                    6    6.    6.
 0    1   1.0  0   2   1.0  0   3   1.0  0   4    1.0  0   5   1.0  0   6    1.0
 1CU1      4       4   1.                                                0.    54.      1
 1    1    1.
 1CU2      5       4   1.                                                0.    54.      1
 1    1    1.
//
/*
```

APPENDIX C OPUS MODEL OUTPUT USING OPUS INPUT DATA

ALL POINTS

SCALE OF X-AXIS

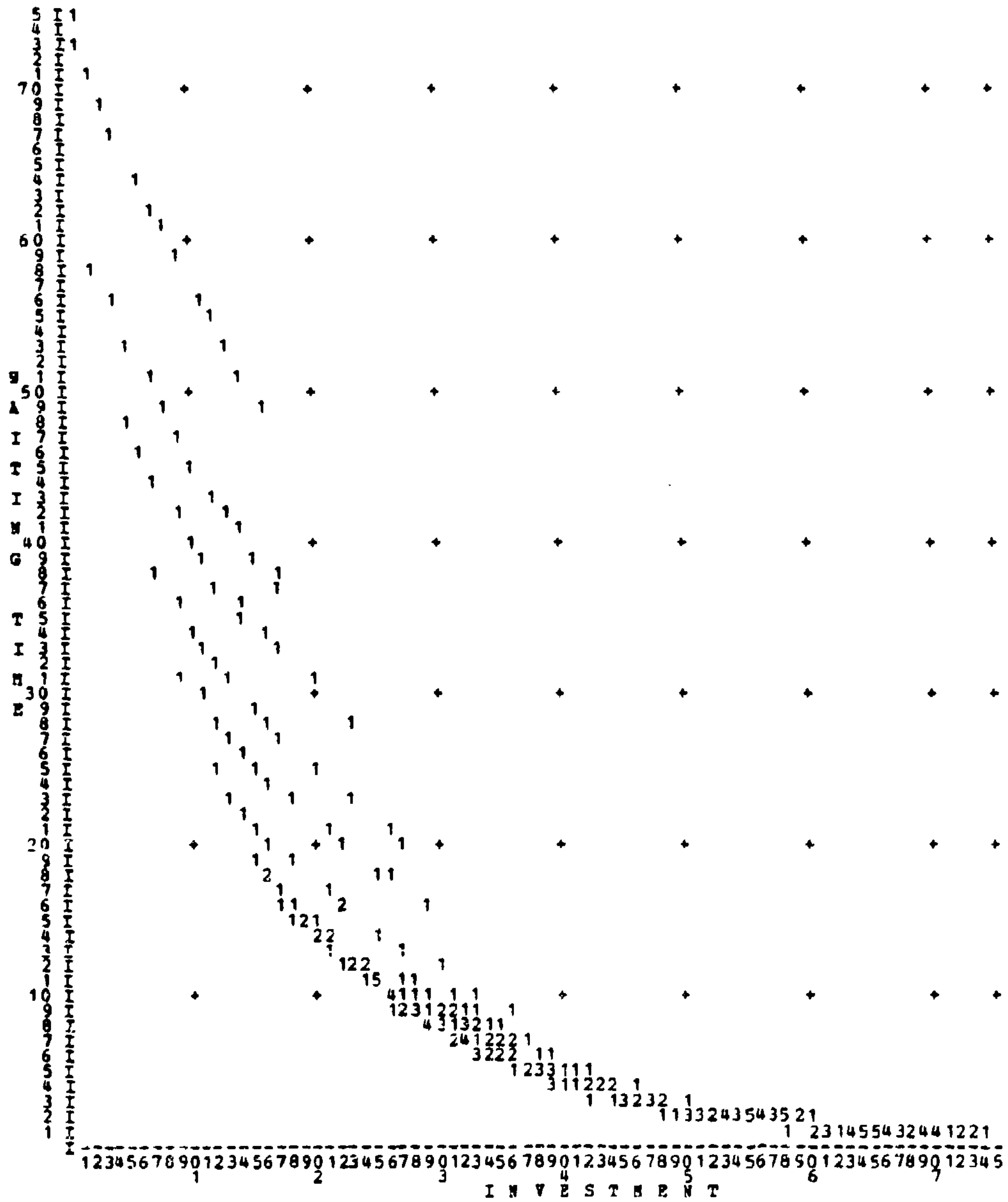
INVESTMENT
MINIMUM = 0.0
STEP LENGTH= 0.18611E+05
MAXIMUM = 0.13772E+07

SCALE OF Y-AXIS

WAITING TIME
MINIMUM = 0.17441E+01
STEP LENGTH= 0.13177E+02
MAXIMUM = 0.97686E+03

COORDINATE AXIS

POINT NO.	INVESTM	WAITING TIME
1	0.0	1.744063
10	167497.2	120.338806
20	353605.3	252.110779
30	539713.4	383.882568
40	725821.5	515.654541
50	911929.6	647.426514
60	1098037.0	779.198486
70	1284145.0	910.970215


WAITING TIME
INVESTMENT

EXAMPLE NO.2 102383   MOE=EXPECTED WAITING TIME PT=INIT PROC   POINT NO. 2

DENOM	TOTAL	INVESTM.	C	B1	B2	A1	A2	DENOM	TOTAL	INVESTM.	C	B1	B2	A1	A2	DENOM	TOTAL	INVESTM.	C	B1	B2	A1	A2
LRU 1	0	0.0	0	0	0	0	0	SRU 1	9	51300.0	7	1	1	0	0	SRU 7	1	5600.0	1	0	0	0	0
LRU 2	2	50200.0	0	1	1	0	0	SRU 2	5	10000.0	3	1	1	0	0	SRU 8	3	26100.0	1	1	1	0	0
LRU 3	0	0.0	0	0	0	0	0	SRU 3	2	5400.0	1	0	1	0	0	SRU 9	3	11700.0	2	0	1	0	0
LRU 4	0	0.0	0	0	0	0	0	SRU 4	10	97000.0	7	1	2	0	0	SRU10	1	4200.0	1	0	0	0	0
LRU 5	0	0.0	0	0	0	0	0	SRU 5	3	16200.0	2	0	1	0	0	SRU11	5	34500.0	4	0	1	0	0
LRU 6	0	0.0	0	0	0	0	0	SRU 6	7	79100.0	5	1	1	0	0								

	AVAILIABILITY PER SYSTEM:	PER SYSTEM AND DEMAND GENERATING STATION CU1	CU2
SYSTEM 1	0.83590	0.82451	0.84097
TOTAL :	0.83590		

INVESTMENT		MEASURE OF EFFECTIVENESS	
TOT INVESTM. =	391300.0	AVAILIABILITY =	0.83590
PERC E S S =	60.7	N O R S =	76.79785
PERC FIRST LEVEL=	0.0	WAITING TIME =	182.06110
PERC LRU =	12.8	RISK OF SHORTAGE =	1.000000
PERC SRU =	87.2	RSK SHRTGE(1ST LVL) =	1.000000

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EXAMPLE NO.2 102383   MOE=EXPECTED WAITING TIME PT=INIT PROC   POINT NO. 6

DENOM	TOTAL	INVESTM.	C	B1	B2	A1	A2	DENOM	TOTAL	INVESTM.	C	B1	B2	A1	A2	DENOM	TOTAL	INVESTM.	C	B1	B2	A1	A2
LRU 1	4	65600.0	0	2	2	0	0	SRU 1	9	51300.0	7	1	1	0	0	SRU 7	1	5600.0	1	0	0	0	0
LRU 2	36	903600.0	0	3	3	1	1	SRU 2	5	10000.0	3	1	1	0	0	SRU 8	3	26100.0	1	1	1	0	0
LRU 3	4	88800.0	0	2	2	0	0	SRU 3	3	8100.0	1	1	1	0	0	SRU 9	4	15600.0	2	1	1	0	0
LRU 4	4	64800.0	0	2	2	0	0	SRU 4	10	97000.0	7	1	2	0	0	SRU10	1	4200.0	1	0	0	0	0
LRU 5	4	227600.0	0	2	2	0	0	SRU 5	4	21600.0	2	1	1	0	0	SRU11	6	41400.0	4	1	1	0	0
LRU 6	7	387100.0	1	3	3	0	0	SRU 6	8	90400.0	5	1	2	0	0								

	AVALIABILITY PER SYSTEM:	PER SYSTEM AND DEMAND GENERATING STATION CU1	CU2
SYSTEM 1	0.97918	0.97988	0.97887
TOTAL :	0.97918		

INVESTMENT		MEASURE OF EFFECTIVENESS	
TOT INVESTM. =	2108800.0	AVAILIABILITY =	0.97918
PERC E S S =	13.9	N O R S =	9.74219
PERC FIRST LEVEL=	35.7	WAITING TIME =	18.50597
PERC LRU =	32.4	RISK OF SHORTAGE =	0.712754
PERC SRU =	17.6	RSK SHRTGE(1ST LVL) =	0.712754

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EXAMPLE NO.2 102383 MCE=EXPECTED WAITING TIME PT=INIT PROC POINT NO. 12

DENOM	TOTAL	INVESTM.	C	B1	B2	A1	A2
LRU 1	34	557600.0	0	2	2	1	1
LRU 2	36	903600.0	0	3	3	1	1
LRU 3	34	754800.0	0	2	2	1	1
LRU 4	34	550800.0	0	2	2	1	1
LRU 5	4	227600.0	0	2	2	0	0
LRU 6	25	1382500.0	1	3	3	0	1

DENOM	TOTAL	INVESTM.	C	B1	B2	A1	A2
SRU 1	9	51300.0	7	1	1	0	0
SRU 2	5	10000.0	3	1	1	0	0
SRU 3	3	8100.0	1	1	1	0	0
SRU 4	10	97000.0	7	1	2	0	0
SRU 5	4	21600.0	2	1	1	0	0
SRU 6	8	90400.0	5	1	2	0	0

DENOM	TOTAL	INVESTM.	C	B1	B2	A1	A2
SRU 7	1	5600.0	1	0	0	0	0
SRU 8	3	26100.0	1	1	1	0	0
SRU 9	4	15600.0	2	1	1	0	0
SRU10	1	4200.0	1	0	0	0	0
SRU11	6	41400.0	4	1	1	0	0

	AVAILABILITY PER SYSTEM:	PER SYSTEM AND DEMAND GENERATING STATION CU1	CU2
SYSTEM 1	0.99283	0.98889	0.99458
TOTAL :	0.99283		

INVESTMENT		MEASURE OF EFFECTIVENESS	
TOT INVESTM. =	4748200.0	AVAILIABILITY =	0.99283
PERC E S S =	6.2	N O R S =	3.35645
PERC FIRST LEVEL=	71.4	WAITING TIME =	6.15679
PERC LRU =	92.2	RISK OF SHORTAGE =	0.235050
PERC SRU =	7.8	RSK SHRTGE(1ST LVL)=	0.235050

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EXAMPLE NO.2 102383 MCE=EXPECTED WAITING TIME PT=INIT PROC POINT NO. 19

DENOM	TOTAL	INVESTM.	C	B1	B2	A1	A2
LRU 1	34	557600.0	0	2	2	1	1
LRU 2	34	1355400.0	0	3	3	1	2
LRU 3	34	754800.0	0	2	2	1	1
LRU 4	34	550800.0	0	2	2	1	1
LRU 5	34	1934600.0	0	2	2	1	1
LRU 6	37	2046100.0	1	3	3	1	1

DENOM	TOTAL	INVESTM.	C	B1	B2	A1	A2
SRU 1	9	51300.0	7	1	1	0	0
SRU 2	5	10000.0	3	1	1	0	0
SRU 3	3	8100.0	1	1	1	0	0
SRU 4	10	97000.0	7	1	2	0	0
SRU 5	4	21600.0	2	1	1	0	0
SRU 6	8	90400.0	5	1	2	0	0

DENOM	TOTAL	INVESTM.	C	B1	B2	A1	A2
SRU 7	1	5600.0	1	0	0	0	0
SRU 8	3	26100.0	1	1	1	0	0
SRU 9	4	15600.0	2	1	1	0	0
SRU10	1	4200.0	1	0	0	0	0
SRU11	6	41400.0	4	1	1	0	0

	AVAILABILITY PER SYSTEM:	PER SYSTEM AND DEMAND GENERATING STATION CU1	CU2
SYSTEM 1	0.99886	0.99885	0.99887
TOTAL :	0.99886		

INVESTMENT		MEASURE OF EFFECTIVENESS	
TOT INVESTM. =	7570600.0	AVAILIABILITY =	0.99886
PERC E S S =	3.9	N O R S =	0.53271
PERC FIRST LEVEL=	82.1	WAITING TIME =	0.05198
PERC LRU =	95.1	RISK OF SHORTAGE =	0.004004
PERC SRU =	4.9	RSK SHRTGE(1ST LVL)=	0.004004

EXAMPLE NO.2 102383 MOE=EXPECTED WAITING TIME PT=INIT PROC POINT NO. 24

DENOM	TOTAL	INVESTM.	C	B1	B2	A1	A2	DENOM	TOTAL	INVESTM.	C	B1	B2	A1	A2	DENOM	TOTAL	INVESTM.	C	B1	B2	A1	A2
LRU 1	34	557600.0	0	2	2	1	1	SRU 1	9	51300.0	7	1	1	0	0	SRU 7	1	5600.0	1	0	0	0	0
LRU 2	66	1656600.0	0	3	3	2	2	SRU 2	5	10000.0	3	1	1	0	0	SRU 8	3	26100.0	1	1	1	0	0
LRU 3	34	754000.0	0	2	2	1	1	SRU 3	3	8100.0	1	1	1	0	0	SRU 9	4	15600.0	2	1	1	0	0
LRU 4	64	1036800.0	0	2	2	2	2	SRU 4	10	97000.0	7	1	2	0	0	SRU10	1	4200.0	1	0	0	0	0
LRU 5	34	1934600.0	0	2	2	1	1	SRU 5	4	21600.0	2	1	1	0	0	SRU11	6	41400.0	4	1	1	0	0
LRU 6	66	3649800.0	1	2	3	2	2	SRU 6	8	90400.0	5	1	2	0	0								

	AVAILABILITY PER SYSTEM:	PER SYSTEM AND DEMAND GENERATING STATION C01	C02
SYSTEM 1	0.99890	0.99890	0.99890
TOTAL :	0.99890		

INVESTMENT		MEASURE OF EFFECTIVENESS	
TOT INVESTM. =	9961500.0	AVAILIABILITY =	0.99890
PERC E S S =	2.9	N O R S =	0.51587
PERC FIRST LEVEL=	36.9	WAITING TIME =	0.01626
PERC LRU =	96.3	RISK OF SHORTAGE =	0.001258
PERC SRU =	3.7	RSK SHRTGE(1ST LVL)=	0.001258

EXAMPLE NO.2 102383 MOE=EXPECTED WAITING TIME PT=INIT PROC

POINT NO.	INVESTMENT	AVAILIABILITY	N O R S	WAITING TIME	RISK OF SHORTAGE
1	0.0	0.47918	243.74573	1000.859	1.00000000
2	391300.00	0.83590	76.79785	782.061	1.00000000
3	697000.00	0.92299	36.03906	75.565	1.00000000
4	1086600.00	0.96513	16.32104	32.328	1.00000000
5	1807600.00	0.97691	10.80762	21.265	0.82766241
6	2108800.00	0.97918	9.74219	1[illegible].506	0.71275365
7	2400400.00	0.98160	8.60938	16.495	0.63340443
8	2594800.00	0.98265	8.11890	15.191	0.58049965
9	2890000.00	0.98446	7.27295	13.699	0.52093172
10	3486400.00	0.98743	5.88403	1[illegible].937	0.41131794
11	3752800.00	0.98836	5.44604	9.786	0.36471289
12	4748200.00	0.99283	3.35645	6.157	0.23505038
13	5355500.00	0.99464	2.50732	3.947	0.14874381
14	6679300.00	0.99871	0.60205	0.196	0.00850741
15	6849600.00	0.99880	0.55372	0.110	0.00657474
16	6926700.00	0.99882	0.55151	0.092	0.00609241
17	7063500.00	0.99884	0.54517	0.075	0.00555573
18	7118800.00	0.99884	0.54297	0.069	0.00537248
19	7570600.00	0.99886	0.53271	0.052	0.00400360
20	7871800.00	0.99887	0.52832	0.041	0.00310790
21	8163400.00	0.99888	0.52612	0.037	0.00281887
22	9158800.00	0.99889	0.51929	0.025	0.00196515
23	9353200.00	0.99889	0.51831	0.023	0.00177772
24	9961500.00	0.99890	0.51587	0.016	0.00125769

APPENDIX C OPUS MODEL USING SESAME INPUT DATA

ALL POINTS

SCALE OF X-AXIS

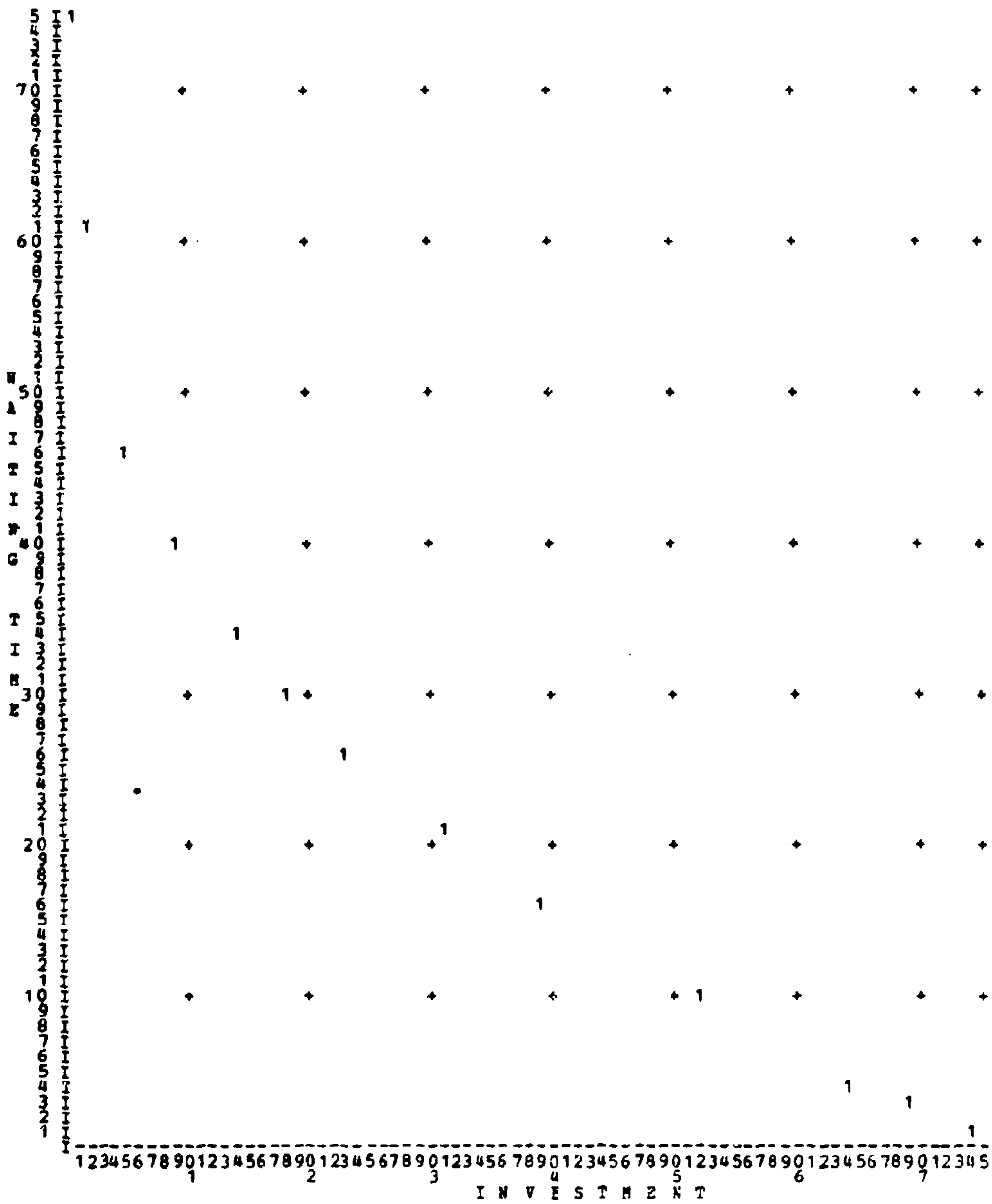
INVESTMENT
MINIMUM = 0.0
STEP LENGTH= 0.29286E+05
MAXIMUM = 0.21672E+07

SCALE OF Y-AXIS

WAITING TIME
MINIMUM = 0.90116E-02
STEP LENGTH= 0.16204E+00
MAXIMUM = 0.12000E+02

COORDINATE AXIS

POINT NO.	INVESTM	WAITING TIME
1	0.0	0.009012
10	263578.3	1.467374
20	556443.2	3.087776
30	849308.0	4.708179
40	1142172.0	6.328582
50	1435037.0	7.948985
60	1727902.0	9.569388
70	2020767.0	11.189791


W A I T I N G T I M E
I N V E S T M E N T

```
         TOT   INVESTM. C1 B1 B2 A1 A2
LRU 1      0        0.0  0  0  0  0  0
LRU 2      0        0.0  0  0  0  0  0
LRU 3      0        0.0  0  0  0  0  0
LRU 4     28   140000.0  0  0  0  1  1
LRU 5      0        0.0  0  0  0  0  0
LRU 6      0        0.0  0  0  0  0  0

         AVAILABILITY
         PER SYSTEM:     PER SYSTEM AND DEMAND GENERATING STATION
                               CU1        CU2
 SYSTEM 1    0.99553    0.99553    0.99553
TOTAL   :    0.99553

INVESTMENT                         MEASURE OF EFFECTIVENESS
----------                         ------------------------
TOT INVESTM.      =     140000.0   AVAILIABILITY        =   0.99553
PERC E S S        =          0.0    N O R S             =   0.12503
PERC FIRST LEVEL=          100.0   WAITING TIME         =   7.37603
PERC LRU          =        100.0   RISK OF SHORTAGE     =  0.615147
PERC SRU          =          0.0   RSK SHRTGE(1ST LVL)=    0.615147

************************************************************************************************************
EXAMPLE NO.2 102383     MOE=EXPECTED WAITING TIME PT=INIT PROC                                POINT NO.  5

         TOT   INVESTM. C1 B1 B2 A1 A2
LRU 1      0        0.0  0  0  0  0  0
LRU 2      0        0.0  0  0  0  0  0
LRU 3     28   266000.0  0  0  0  1  1
LRU 4     28   140000.0  0  0  0  1  1
LRU 5     28   263200.0  0  0  0  1  1
LRU 6      0        0.0  0  0  0  0  0

         AVAILABILITY
         PER SYSTEM:     PER SYSTEM AND DEMAND GENERATING STATION
                               CU1        CU2
 SYSTEM 1    0.99728    0.99728    0.99728
TOTAL   :    0.99728

INVESTMENT                         MEASURE OF EFFECTIVENESS
----------                         ------------------------
TOT INVESTM.      =     669200.0   AVAILIABILITY        =   0.99728
PERC E S S        =          0.0    N O R S             =   0.07629
PERC FIRST LEVEL=          100.0   WAITING TIME         =   4.10138
PERC LRU          =        100.0   RISK OF SHORTAGE     =  0.342387
PERC SRU          =          0.0   RSK SHRTGE(1ST LVL)=    0.342387

************************************************************************************************************
```

```
*******************************************************************************************************
EXAMPLE NO.2 102383     MOE=EXPECTED WAITING TIME PT=INIT PROC                          POINT NO.  9

          TOT   INVESTM.  C1 B1 B2 A1 A2
LRU 1      28   719600.0   0  0  0  1  1
LRU 2      28   294000.0   0  0  0  1  1
LRU 3      28   266000.0   0  0  0  1  1
LRU 4      28   140000.0   0  0  0  1  1
LRU 5      28   263200.0   0  0  0  1  1
LRU 6      28   484400.0   0  0  0  1  1

          AVAILABILITY
          PER SYSTEM:     PER SYSTEM AND DEMAND GENERATING STATION
                               CU1        CU2
 SYSTEM 1   0.99946      0.95946    0.95946
TOTAL   :   0.99946

INVESTMENT                              MEASURE OF EFFECTIVENESS
----------                              ------------------------
TOT INVESTM.     =     2167200.0        AVAILIABILITY        =     0.99946
PERC B S S       =           0.0          N O R S            =     0.01514
PERC FIRST LEVEL=          100.0        WAITING TIME         =     0.00901
PERC LRU         =         100.0        RISK OF SHORTAGE     =    0.001502
PERC SRU         =           0.0        RSK SHRTGE(1ST LVL)  =    0.001502
*******************************************************************************************************


*******************************************************************************************************

EXAMPLE NO.2 102383     MOE=EXPECTED WAITING TIME PT=INIT PROC

POINT NO.   INVESTMENT   AVAILIABILITY      N O R S   WAITING TIME   RISK OF SHORTAGE

    1              0.0        0.99309      0.19359         12.000        1.00000000
    2        140000.00        0.99553      0.12503          7.376        0.61514711
    3        273000.00        0.99608      0.10963          6.340        0.52887475
    4        406000.00        0.99663      0.09422          5.304        0.44260234
    5        669200.00        0.99728      0.07629          4.101        0.34238660
    6        911400.00        0.99773      0.06351          3.245        0.27102333
    7       1153600.00        0.99819      0.05072          2.388        0.19966024
    8       1873200.00        0.99916      0.02354          0.571        0.04836018
    9       2167200.00        0.99546      0.01514          0.009        0.00150216
*******************************************************************************************************
```

APPENDIX D SESAME OUTPUT USING OPUS INPUT DATA


```
SESAME 5/17/83
ENTER CONTRL VALUES IN NAMELIST FMT
 &contrl iout=2, mctlf=39, mttr=2.25, target=.01 &end

CONTROL PARAMETERS-
 AVMIN   AVMAX  CONDEL ICUT IPOL UNCEIL MCTBF   MTTR          TARGET  RYEARS
0.50000 0.99999 120.0    2    1   0.65   39.0   2.25          0.0100   1.00

ASYMMETRICAL STRUCTURE
3 CGS1
2 BDS1
1 A101    17.    12    12
2 BDS2
1 A201    17.    18    18

END ITEM AND WEAPON SYSTEM PARAMETERS-
BSC  BEINS  DEMS    URR    OPSL      PPCC   IDEND
 6.    0.   30.  1.000  30. 30. 30.

    CLMRTS          O D P S        O S T S   VSYS AREA
 30.  2.  1.     17.255.510.     4. 12. 99.    V    C

PART IDENT  SC AR LRU  UNIT PR       UPNHA         FF    REPR FND ESS ......RTD...... ------MTD------ .....REPCYC....
C00000001    S  C  L     16400           0      94.60  0.0    PAA   1  80  20   0   0  80  20   0   0   0   5  67   0

WHOLESALE STOCK     0

AVAILBILITY AND STOCK BY UNIT AT ECHELON 1
A101 1.00000             1.  A101  1.00000         1.  A101 1.00000          1.  A101 1.00000          1.  A101 1.00000
A101 1.00000             1.  A101  1.00000         1.  A101 1.00000          1.  A101 1.00000          1.  A101 1.00000
A101 1.00000             1.  A101  1.00000         1.  A201 1.00000          1.  A201 1.00000          1.  A201 1.00000
A201 1.00000             1.  A201  1.00000         1.  A201 1.00000          1.  A201 1.00000          1.  A201 1.00000
A201 1.00000             1.  A201  1.00000         1.  A201 1.00000          1.  A201 1.00000          1.  A201 1.00000
A201 1.00000             1.  A201  1.00000         1.  A201 1.00000          1.  A201 1.00000          1.  A201 1.00000
 STOCK BY UNIT AT ECHELON 2
BDS1                     1.  BDS2                  1.
 STOCK BY UNIT AT ECHELON 3
CGS1                     0.

000000002    S  C  L     25100           0     275.10  0.0    PAA   1  70  30   0   0  70  30   0   0   0   5  67   0

WHOLESALE STOCK     0

AVAILBILITY AND STOCK BY UNIT AT ECHELON 1
A101 1.00000             1.  A101  1.00000         1.  A101 1.00000          1.  A101 1.00000          1.  A101 1.00000
A101 1.00000             1.  A101  1.00000         1.  A101 1.00000          1.  A101 1.00000          1.  A101 1.00000
A101 1.00000             1.  A101  1.00000         1.  A201 1.00000          1.  A201 1.00000          1.  A201 1.00000
A201 1.00000             1.  A201  1.00000         1.  A201 1.00000          1.  A201 1.00000          1.  A201 1.00000
A201 1.00000             1.  A201  1.00000         1.  A201 1.00000          1.  A201 1.00000          1.  A201 1.00000
A201 1.00000             1.  A201  1.00000         1.  A201 1.00000          1.  A201 1.00000          1.  A201 1.00000
 STOCK BY UNIT AT ECHELON 2
BDS1                     2.  BDS2                  4.
 STOCK BY UNIT AT ECHELON 3
CGS1                     0.

000000003    S  C  L     22200           0     111.00  0.0    PAA   1  70  30   0   0  70  30   0   0   0   5  67   0

WHOLESALE STOCK     0

AVAILBILITY AND STOCK BY UNIT AT ECHELON 1
A101 1.00000             1.  A101  1.00000         1.  A101 1.00000          1.  A101 1.00000          1.  A101 1.00000
A101 1.00000             1.  A101  1.00000         1.  A101 1.00000          1.  A101 1.00000          1.  A101 1.00000
A101 1.00000             1.  A101  1.00000         1.  A201 1.00000          1.  A201 1.00000          1.  A201 1.00000
A201 1.00000             1.  A201  1.00000         1.  A201 1.00000          1.  A201 1.00000          1.  A201 1.00000
A201 1.00000             1.  A201  1.00000         1.  A201 1.00000          1.  A201 1.00000          1.  A201 1.00000
A201 1.00000             1.  A201  1.00000         1.  A201 1.00000          1.  A201 1.00000          1.  A201 1.00000
 STOCK BY UNIT AT ECHELON 2
BDS1                     1.  BDS2                  1.
 STOCK BY UNIT AT ECHELON 3
```

```
CGS1               0.
000C00004    S  C  L     16200          0     126.00  0.0    PAA   1  80  20   0   0  80  20   0   0   0   5  67   0
WHOLESALE STOCK     0
AVAILBILITY AND STOCK BY UNIT AT ECHELON 1
A101 1.00000            1.  A101 1.00000      1.  A101 1.00000        1.  A101 1.00000        1.  A101 1.00000        1.
A101 1.00000            1.  A101 1.00000      1.  A101 1.00000        1.  A101 1.00000        1.  A101 1.00000        1.
A101 1.00000            1.  A101 1.00000      1.  A201 1.00000        1.  A201 1.00000        1.  A201 1.00000        1.
A201 1.00000            1.  A201 1.00000      1.  A201 1.00000        1.  A201 1.0000         1.  A2C1 1.00000        1.
A201 1.00000            1.  A201 1.00000      1.  A201 1.00000        1.  A201 1.00000        1.  A201 1.00000        1.
A201 1.00000            1.  A201 1.00000      1.  A201 1.00000        1.  A201 1.00000        1.  A2C1 1.00000        1.
 STOCK BY UNIT AT ECHELON 2
BDS1               1.  BDS2                   1.
 STOCK BY UNIT AT ECHELON 3
CGS1               0.
000C00005    S  C  L     59600          0     136.70  0.0    PAA   1  60  30  10   0  60  30  10   0   0   5  67   0
WHOLESALE STOCK     0
AVAILBILITY AND STOCK BY UNIT AT ECHELON 1
A101 1.00000            1.  A101 1.00000      1.  A101 1.00000        1.  A101 1.00000        1.  A101 1.00000        1.
A101 1.00000            1.  A101 1.00000      1.  A101 1.00000        1.  A101 1.00000        1.  A101 1.00000        1.
A101 1.00000            1.  A101 1.00000      1.  A201 1.00000        1.  A201 1.00000        1.  A201 1.00000        1.
A201 1.00000            1.  A201 1.00000      1.  A201 1.00000        1.  A201 1.00000        1.  A2C1 1.00000        1.
A201 1.00000            1.  A201 1.00000      1.  A201 1.00000        1.  A201 1.00000        1.  A201 1.00000        1.
A201 1.00000            1.  A201 1.00000      1.  A201 1.00000        1.  A201 1.00000        1.  A2C1 1.00000        1.
 STOCK BY UNIT AT ECHELON 2
BDS1               1.  BDS2                   2.
 STOCK BY UNIT AT ECHELON 3
CGS1              13.
000C00006    S  C  L     55300          0     206.70  0.0    PAA   1  60  30  10   0  60  30  10   0   0   5  67   0
WHOLESALE STOCK     0
AVAILBILITY AND STOCK BY UNIT AT ECHELON 1
A101 1.00000            1.  A101 1.00000      1.  A101 1.00000        1.  A101 1.00000        1.  A1C1 1.00000        1.
A101 1.00000            1.  A101 1.00000      1.  A101 1.00000        1.  A101 1.00000        1.  A101 1.00000        1.
A101 1.00000            1.  A101 1.00000      1.  A201 1.00000        1.  A201 1.00000        1.  A201 1.00000        1.
A201 1.00000            1.  A201 1.00000      1.  A201 1.00000        1.  A201 1.00000        1.  A2C1 1.00000        1.
A201 1.00000            1.  A201 1.00000      1.  A201 1.00000        1.  A201 1.00000        1.  A201 1.00000        1.
A201 1.00000            1.  A201 1.00000      1.  A201 1.00000        1.  A201 1.00000        1.  A201 1.00000        1.
 STOCK BY UNIT AT ECHELON 2
BDS1               2.  BDS2                   3.
 STOCK BY UNIT AT ECHELON 3
CGS1              19.
C00C00101    S  C  N      5700      22200      18.10  0.0    PAA   4  80  10  10   0  80  10  10   0   0   6  69   0
WHOLESALE STOCK     0
AVAILBILITY AND STOCK BY UNIT AT ECHELON 1
A101 0.99999            0.  A101 0.99999      0.  A101 0.99999        0.  A101 0.99999        0.  A101 0.99999        0.
A101 0.99999            0.  A101 0.99999      0.  A101 0.99999        0.  A101 0.99999        0.  A101 0.99999        0.
A101 0.99999            0.  A101 0.99999      0.  A201 0.99999        0.  A201 0.99999        0.  A201 0.99999        0.
A201 0.99999            0.  A201 0.99999      0.  A201 0.99999        0.  A201 0.99999        0.  A2C1 0.99999
A201 0.99999            0.  A201 0.99999      0.  A201 0.99999        0.  A201 0.99999        0.  A201 0.99999
A201 0.99999            0.  A201 0.99999      0.  A201 0.99999        0.  A201 0.99999        0.  A2C1 0.99999        0.
 STOCK BY UNIT AT ECHELON 2
BDS1               0.  BDS2                   0.
 STOCK BY UNIT AT ECHELON 3
CGS1               2.
C00C00102    S  C  N      2000      16400       5.30  0.0    PAA   4  80  10  10   0  80  10  10   0   0   6  69   0
WHOLESALE STOCK     0
AVAILBILITY AND STOCK BY UNIT AT ECHELON 1
A101 1.00000            0.  A101 1.00000      0.  A101 1.00000        0.  A101 1.00000        0.  A1C1 1.00000
```

```
A101 1.00000          0.  A101 1.00000        0.  A1C1 1.00000        0.  A101 1.00000        0.  A101 1.00000        0.
A101 1.00000          0.  A101 1.00000        0.  A201 1.00000        0.  A201 1.00000        0.  A201 1.00000        0.
A201 1.00000          0.  A201 1.00000        0.  A201 1.00000        0.  A201 1.00000        0.  A201 1.00000        0.
A201 1.00000          0.  A201 1.00000        0.  A201 1.00000        0.  A201 1.00000        0.  A201 1.00000        0.
A201 1.C0000          0.  A201 1.00000        0.  A201 1.00000        0.  A201 1.00000        0.  A2C1 1.00000        0.
 STOCK BY UNIT AT ECHELON 2
BDS1                  0.  BDS2                0.
 STOCK BY UNIT AT ECHELON 3
CGS1                  0.

C00C00103   S  C  N    2700      16400    1.40  0.0   PAA   4  80  10  10   0  80  10  10   0   0   6  69   0

WHOLESALE STOCK    0

AVAILBILITY AND STOCK BY UNIT AT ECHELON 1
A101 1.0000C          0.  A101 1.00000        0.  A101 1.00000        0.  A101 1.00000        0.  A101 1.00000        0.
A101 1.00000          0.  A101 1.00000        0.  A101 1.00000        0.  A101 1.00000        0.  A101 1.00000        0.
A101 1.00000          0.  A101 1.00000        0.  A201 1.00000        0.  A201 1.00000        0.  A201 1.00000        0.
A201 1.C0000          0.  A201 1.00000        0.  A201 1.00000        0.  A201 1.00000        0.  A2C1 1.00000        0.
A201 1.00000          0.  A201 1.00000        0.  A201 1.00000        0.  A201 1.00000        0.  A201 1.00000        0.
A201 1.C0000          0.  A201 1.00000        0.  A201 1.00000        0.  A201 1.00000        0.  A201 1.00000        0.
 STOCK BY UNIT AT ECHELON 2
BDS1                  0.  BDS2                0.
 STOCK BY UNIT AT ECHELON 3
CGS1                  0.

C000001C4   S  C  N    9700      25100   36.80  0.0   PAA   4  80  10  10   0  80  10  10   0   0   6  69   0

WHOLESALE STOCK    0

AVAILBILITY AND STOCK BY UNIT AT ECHELON 1
A101 0.99998          0.  A101 0.99998        0.  A101 0.99998        0.  A101 0.99998        0.  A1C1 0.99998        0.
A101 0.99998          0.  A101 0.99998        0.  A101 0.99998        0.  A101 0.99998        0.  A101 0.99998        0.
A1C1 0.99998          0.  A101 0.99998        0.  A201 0.99998        0.  A201 0.99998        0.  A201 0.99998        0.
A201 0.99998          0.  A201 0.99998        0.  A201 0.99998        0.  A201 0.99998        0.  A2C1 0.99998        0.
A201 0.99998          0.  A201 0.99998        0.  A201 0.99998        0.  A201 0.99998        0.  A201 0.99998        0.
A201 0.99998          0.  A201 0.99998        0.  A201 0.99998        0.  A201 0.99998        0.  A201 0.99998        0.
 STOCK BY UNIT AT ECHELON 2
BDS1                  1.  BDS2                1.
 STOCK BY UNIT AT ECHELON 3
CGS1                  4.

C00C00105   S  C  N    5400      22200    9.60  0.0   PAA   4  80  10  10   0  80  10  10   0   0   6  69   0

WHOLESALE STOCK    0

AVAILBILITY AND STOCK BY UNIT AT ECHELON 1
A101 0.99999          0.  A101 0.99999        0.  A101 0.99999        0.  A101 0.99999        0.  A1C1 0.99999        0.
A101 0.99999          0.  A101 0.99999        0.  A101 0.99999        0.  A101 0.99999        0.  A101 0.99999        0.
A101 0.99999          0.  A101 0.99999        0.  A201 0.99999        0.  A201 0.99999        0.  A201 0.99999        0.
A201 0.99999          0.  A201 0.99999        0.  A201 0.99999        0.  A201 0.99999        0.  A2C1 0.99999        0.
A201 0.99999          0.  A201 0.99999        0.  A201 0.99999        0.  A201 0.99999        0.  A201 0.99999        0.
A201 0.99999          0.  A201 0.99999        0.  A201 0.99999        0.  A201 C.99999        0.  A201 0.99999        0.
 STOCK BY UNIT AT ECHELON 2
BDS1                  0.  BDS2                0.
 STOCK BY UNIT AT ECHELON 3
CGS1                  0.

C00C00106   S  C  N   11300      59600   29.80  0.0   PAA   4  80  10  10   0  80  10  10   0   0   6  69   0

WHOLESALE STOCK    0

AVAILBILITY AND STOCK BY UNIT AT ECHELON 1
A101 0.99998          0.  A101 0.99998        0.  A101 0.99998        0.  A101 0.99998        0.  A1C1 0.99998        0.
A101 0.99998          0.  A101 0.99998        0.  A101 0.99998        0.  A101 0.99998        0.  A101 0.99998        0.
A101 0.99998          0.  A101 0.99998        0.  A201 0.99998        0.  A20. 0.99998        0.  A201 0.99998        0.
A201 0.99998          0.  A201 0.99998        0.  A201 0.99998        0.  A201 0.99998        0.  A2C1 0.99998        0.
A201 0.99998          0.  A201 0.99998        0.  A201 0.99998        0.  A201 0.99998        0.  A201 0.99998        0.
A201 0.99998          0.  A201 0.99998        0.  A201 0.99998        0.  A201 0.99998        0.  A2C1 0.99998        0.
 STOCK BY UNIT AT ECHELON 2
BDS1                  1.  BDS2                1.
 STOCK BY UNIT AT ECHELON 3
```

```
CGS1            3.
C00C00107   S  C  M     5600      59600     8.80  0.0    PAA   4  80  10  10   0  80  10  10   0   0   6  69   0
WHOLESALE STOCK     0
AVAILBILITY AND STOCK BY UNIT AT ECHELON 1
A101 0.99999            0.  A101 0.99999      0.  A101 0.99999        0.  A101 0.99999        0.  A1C1 0.99999        0.
A101 0.99999            0.  A101 0.99999      0.  A101 0.99999        0.  A101 0.99999        0.  A101 0.99999        0.
A101 0.99999            0.  A101 0.99999      0.  A201 0.99999        0.  A201 0.99999        0.  A201 0.99999        0.
A201 0.59999            0.  A201 0.99999      0.  A201 0.99999        0.  A201 0.99999        0.  A201 0.99999        0.
A201 0.99999            0.  A201 0.99999      0.  A201 0.99999        0.  A201 0.99999        0.  A201 0.99999        0.
A201 0.99999            0.  A201 0.99999      0.  A201 0.99999        0.  A201 0.99999        0.  A201 0.99999        0.
 STOCK BY UNIT AT ECHELON 2
BDS1                    0.  BDS2              0.
 STOCK BY UNIT AT ECHELON 3
CGS1                    0.
C00000108   S  C  M     8700      59600    19.30  0.0    PAA   4  80  10  10   0  80  10  10   0   0   6  69   0
WHOLESALE STOCK     0
AVAILBILITY AND STOCK BY UNIT AT ECHELON 1
A101 0.99999            0.  A101 0.99999      0.  A101 0.99999        0.  A101 0.99999        0.  A101 0.99999        0.
A101 0.99999            0.  A101 0.99999      0.  A101 0.99999        0.  A1C1 0.99999        0.  A101 0.99999        0.
A101 0.99999            0.  A101 0.99999      0.  A201 0.99999        0.  A201 0.99999        0.  A201 0.99999        0.
A201 0.99999            0.  A201 0.99999      0.  A201 0.99999        0.  A201 0.99999        0.  A2C1 0.99999        0.
A201 0.99999            0.  A201 0.99999      0.  A201 0.99999        0.  A201 0.99999        0.  A201 0.99999        0.
A201 0.99999            0.  A201 0.99999      0.  A201 0.99999        0.  A201 0.99999        0.  A201 0.99999        0.
 STOCK BY UNIT AT ECHELON 2
BDS1                    0.  BDS2              0.
 STOCK BY UNIT AT ECHELON 3
CGS1                    2.
C00000109   S  C  M     3900      55300    14.90  0.0    PAA   4  80  10  10   0  80  10  10   0   0   6  69   0
WHOLESALE STOCK     0
AVAILBILITY AND STOCK BY UNIT AT ECHELON 1
A101 0.99999            0.  A101 0.99999      0.  A101 0.99999        0.  A101 0.99999        0.  A101 0.99999        0.
A101 0.99999            0.  A101 0.99999      0.  A101 0.99999        0.  A101 0.99999        0.  A1C1 0.99999        0.
A101 0.99999            0.  A101 0.99999      0.  A201 0.99999        0.  A201 0.99999        0.  A201 0.99999        0.
A201 0.99999            0.  A201 0.99999      0.  A201 0.99999        0.  A201 0.99999        0.  A201 0.99999        0.
A201 0.99999            0.  A201 0.99999      0.  A201 0.99999        0.  A201 0.99999        0.  A201 0.99999        0.
A201 0.99999            0.  A201 0.99999      0.  A201 0.99999        0.  A201 0.99999        0.  A201 0.99999        0.
 STOCK BY UNIT AT ECHELON 2
BDS1                    0.  BDS2              0.
 STOCK BY UNIT AT ECHELON 3
CGS1                    1.
000000110   S  C  M     4200      55300    10.50  0.0    PAA   4  80  10  10   0  80  10  10   0   0   6  69   0
WHOLESALE STOCK     0
AVAILBILITY AND STOCK BY UNIT AT ECHELON 1
A101 0.99999            0.  A101 0.99999      0.  A101 0.99999        0.  A101 0.99999        0.  A101 0.99999        0.
A101 0.99999            0.  A101 0.99999      0.  A101 0.99999        0.  A101 0.99999        0.  A101 0.99999        0.
A101 0.99999            0.  A101 0.99999      0.  A201 0.99999        0.  A201 0.99999        0.  A201 0.99999        0.
A201 0.99999            0.  A201 0.99999      0.  A201 0.99999        0.  A201 0.99999        0.  A201 0.99999        0.
A201 0.99999            0.  A201 0.99999      0.  A201 0.99999        0.  A201 0.99999        0.  A201 0.99999        0.
A201 0.99999            0.  A201 0.99999      0.  A201 0.99999        0.  A201 0.99999        0.  A201 0.99999        0.
 STOCK BY UNIT AT ECHELON 2
BDS1                    0.  BDS2              0.
 STOCK BY UNIT AT ECHELON 3
CGS1                    0.
000000111   S  C  M     6900      55300    24.50  0.0    PAA   4  80  10  10   0  80  10  10   0   0   6  69   0
WHOLESALE STOCK     0
AVAILBILITY AND STOCK BY UNIT AT ECHELON 1
A101 0.99998            0.  A101 0.99998      0.  A101 0.99998        0.  A101 0.99998        0.  A101 0.99998
```

```
                                                                                                   PAGE 005

A101 0.99998        0.  A101 0.99998        0.  A101 0.99998        0.  A101 0.99998        0.  A101 0.99998        0.
A101 0.99998        0.  A101 0.99998        0.  A201 0.99998        0.  A201 0.99998        0.  A201 0.99998        0.
A201 0.99998        0.  A201 0.99998        0.  A201 0.99998        0.  A201 0.99998        0.  A201 0.99998        0.
A201 0.99998        0.  A201 0.99998        0.  A201 0.99998        0.  A201 0.99998        0.  A201 0.99998        0.
A201 0.99998        0.  A201 0.99998        0.  A201 0.99998        0.  A201 0.99998        0.  A201 0.99998        0.
 STOCK BY UNIT AT ECHELON 2
BDS1                0.  BDS2                1.
 STOCK BY UNIT AT ECHELON 3
CGS1                2.

   TARGET=              0.010000

   THE NUMBER OF CURVE PARAMETERS TESTED=    1
    SIP SATISFIED TARGET
CURVE PARAMETER    AVAILABILITY     RETAIL COST
      0.01           0.945287       8553100.00

   17 ITEMS

                    * * * * *   SESAME SUMMARY REPORT :              * * * * *

AREA = C  -   CURVE PARAMETER = $        0.01
                                       RETAIL                                                           STOCKAGE CODES
                                NSNS STK                  NSNS STK
      ECHELON   CLNNTS   OOPS      PAA        $PAA          ASP       $ASP                      E      S      A      U      D TOTAL
      ORG        30.      17.       6    5844000.00          0       0.0             LRUS        0      6      0
      DSU         2.     255.       9     764400.00          0       0.0         NON LRUS               0      0      0      0
      GSU         1.     510.       8    1944700.00          0       0.0         NON ESSEN             11                         1
                                                                             THIS RUN HAD     6 LRUS IN THE INPUT DATA.
       TOTAL RETAIL $                    8553100.00                  0.0          0 LRUS RECEIVED STOCKAGE GREATER THAN SIP.

              MCTBF        MCTBF                 SUPPLY        OPERATIONAL
      MTTR   (INPUT)     (DERIVED)    MLDT    AVAILABILITY    AVAILABILITY
      2.25     39.          38.       0.007     0.999815        0.945287
                                       RESULTS BY UNIT FOR ASYMMETRIC STRUCTURE

AVAILIBILITY AND $STOCK BY UNIT AT ECHELON 1
A101 0.94529     194800.  A101 0.94529   194800.  A101 0.94529   194800.  A101 0.94529   194800.  A101 0.94529   194800.
A101 0.94529     194800.  A101 0.94529   194800.  A101 0.94529   194800.  A101 0.94529   194800.  A101 0.94529   194800.
A101 0.94529     194800.  A101 0.94529   194800.  A201 0.94529   194800.  A201 0.94529   194800.  A201 0.94529   194800.
A201 0.94529     194800.  A201 0.94529   194800.  A201 0.94529   194800.  A201 0.94529   194800.  A201 0.94529   194800.
A201 0.94529     194800.  A201 0.94529   194800.  A201 0.94529   194800.  A201 0.94529   194800.  A201 0.94529   194800.
A201 0.94529     194800.  A201 0.94529   194800.  A201 0.94529   194800.  A201 0.94529   194800.  A201 0.94529   194800.

$STOCK BY UNIT AT ECHELON 2
BDS1          296200.  BDS2           468200.

$STOCK BY UNIT AT ECHELON 3
CGS1         1944700.

      WHOLESALE BREAKOUT  REPAIR PIPELINE   CONSUMPTION
                               0.0             0.0  PAA
                               0.0             0.0  ASP

      THESE RESULTS REFLECT THE COST OF PROVISIONING THE CLNNTS IN THE AREAS INDICATED ABOVE
                     PLUS THE COST OF $         0. AT THE WHOLESALE LEVEL FOR 1.00 YEARS

         CURPAR =        0.01
     ASP BUDGET =        0.0
     PAA BUDGET =  8553100.00
     TOT BUDGET =  8553100.00
R: T=10.69/12.70 10:56:15
```

APPENDIX D SESAME OUTPUT USING SESAME INPUT DATA


```
SESAME 5/17/83
ENTER CONTRL VALUES IN NAMELIST FMT
 &control iout=2, mctbf=75, mttr=2.5,target=.01 &end

CONTROL PARAMETERS-
  AVMIN   AVMAX  CONDEL IOUT IPOL WHOFIL MCTBF   MTTR          TARGET DYEARS
 0.50000 0.99999 120.0    2    1   0.85   75.0   2.50          0.0100   1.00

ASYMMETRICAL STRUCTURE
3 GSU1
2 DSU1
1 ORG1     6.    14    14
2 DSU2
1 ORG2     6.    14    14

END ITEM AND WEAPON SYSTEM PARAMETERS-
RSC  RDEMS  DEMS    DRR      OPSL       PPCC   IDEND
 6.    0.    28.   1.000  30. 30. 30.

   CLMNTS        O U P S       O S I S   VSYS AREA
 28.  2.  1.    6. 84.168.    1.  3. 60.   V    C

PART IDENT  SC AR LRD  UNIT PR        DPMHA       FF    REPR FND ESS ......RTD.....  ------NTD------  .....REPCYC....

ITEM1         S  C  L     25700           0    71.00  0.0700 PAA   1 100   0   0   0   0  93   0   0   1  30 100   0

WHOLESALE STOCK       1

AVAILBILITY AND STOCK BY UNIT AT ECHELON 1
ORG1 0.99808             0.  ORG1 0.99808         0.  ORG1 0.99808         0.  ORG1 0.99808         0.  ORG1 0.99808
ORG1 0.99808             0.  ORG1 0.99808         0.  ORG1 0.99808         0.  ORG1 0.99808         0.  ORG1 0.99808
ORG1 0.99808             0.  ORG1 0.99808         0.  ORG1 0.99808         0.  ORG1 0.99808         0.  ORG2 0.99808
ORG2 0.99808             0.  ORG2 0.99808         0.  ORG2 0.99808         0.  ORG2 0.99808         0.  ORG2 0.99808
ORG2 0.99808             0.  ORG2 0.99808         0.  ORG2 0.99808         0.  ORG2 0.99808         0.  ORG2 0.99808
ORG2 0.99808             0.  ORG2 0.99808         0.  ORG2 0.99808         0.
 STOCK BY UNIT AT ECHELON 2
DSU1                     5.  DSU2                 5.
 STOCK BY UNIT AT ECHELON 3
GSU1                     2.

ITEM2         S  C  L     10500           0    22.00  0.0700 PAA   1   0 100   0   0   0  93   0   0   1  30 100   0

WHOLESALE STOCK       1

AVAILBILITY AND STOCK BY UNIT AT ECHELON 1
ORG1 0.99944             0.  ORG1 0.99944         0.  ORG1 0.99944         0.  ORG1 0.99944         0.  ORG1 0.99944
ORG1 0.99944             0.  ORG1 0.99944         0.  ORG1 0.99944         0.  ORG1 0.99944         0.  ORG1 0.99944
ORG1 0.99944             0.  ORG1 0.99944         0.  ORG1 0.99944         0.  ORG1 0.99944         0.  ORG2 0.99944
ORG2 0.99944             0.  ORG2 0.99944         0.  ORG2 0.99944         0.  ORG2 0.99944         0.  ORG2 0.99944
ORG2 0.99944             0.  ORG2 0.99944         0.  ORG2 0.99944         0.  ORG2 0.99944         0.  ORG2 0.99944
ORG2 0.99944             0.  ORG2 0.99944         0.  ORG2 0.99944         0.
 STOCK BY UNIT AT ECHELON 2
DSU1                     2.  DSU2                 2.
 STOCK BY UNIT AT ECHELON 3
GSU1                     1.

ITEM3         S  C  L      9500           0    81.00  0.0700 PAA   1   0 100   0   0   0  93   0   0   1  30 100   0

WHOLESALE STOCK       1

AVAILBILITY AND STOCK BY UNIT AT ECHELON 1
ORG1 0.99851             0.  ORG1 0.99851         0.  ORG1 0.99851         0.  ORG1 0.99851         0.  ORG1 0.99851
ORG1 0.99851             0.  ORG1 0.99851         0.  ORG1 0.99851         0.  ORG1 0.99851         0.  ORG1 0.99851
ORG1 0.99851             0.  ORG1 0.99851         0.  ORG1 0.99851         0.  ORG1 0.99851         0.  ORG2 0.99851
ORG2 0.99851             0.  ORG2 0.99851         0.  ORG2 0.99851         0.  ORG2 0.99851         0.  ORG2 0.99851
ORG2 0.99851             0.  ORG2 0.99851         0.  ORG2 0.99851         0.  ORG2 0.99851         0   ORG2 0.99851
ORG2 0.99851             0.  ORG2 0.99851         0.  ORG2 0.99851         0.
 STOCK BY UNIT AT ECHELON 2
DSU1                     6.  DSU2                 6.
 STOCK BY UNIT AT ECHELON 3
```

```
GSU1               2.

ITEM4        S  C  L     5000          0    181.00  0.0     PAA    1 100   0   0   0   0  99   0   0   1  30 100   0

WHOLESALE STOCK     0

AVAILBILITY AND STOCK BY UNIT AT ECHELON 1
ORG1 0.99974            1.   ORG1 0.99974         1.  ORG1 0.99974          1.  ORG1 0.99974          1.  ORG1 0.99974
ORG1 0.99974            1.   ORG1 0.99974         1.  ORG1 0.99974          1.  ORG1 0.99974          1.  ORG1 0.99974
ORG1 0.99974            1.   ORG1 0.99974         1.  ORG1 0.99974          1.  ORG1 0.99974          1.  ORG2 0.99974
ORG2 0.99974            1.   ORG2 0.99974         1.  ORG2 0.99974          1.  ORG2 0.99974          1.  ORG2 0.99974
ORG2 0.99974            1.   ORG2 0.99974         1.  ORG2 0.99974          1.  ORG2 0.99974          1.  ORG2 0.99974
ORG2 0.99974            1.   ORG2 0.99974         1.  ORG2 0.99974          1.
 STOCK BY UNIT AT ECHELON 2
DSU1                   13.   DSU2                13.
 STOCK BY UNIT AT ECHELON 3
GSU1                    1.

ITEM5        S  C  L     9400          0     47.00  0.0700 PAA    1 100   0   0   0   0   0  93   0   1  30 100   0

WHOLESALE STOCK     1

AVAILBILITY AND STOCK BY UNIT AT ECHELON 1
ORG1 0.99837            0.   ORG1 0.99837         0.  ORG1 0.99837          0.  ORG1 0.99837          0.  ORG1 0.99837
ORG1 0.99837            0.   ORG1 0.99837         0.  ORG1 0.99837          0.  ORG1 0.99837          0.  ORG1 0.99837
ORG1 0.99837            0.   ORG1 0.99837         0.  ORG1 0.99837          0.  ORG1 0.99837          0.  ORG2 0.99837
ORG2 0.99837            0.   ORG2 0.99837         0.  ORG2 0.99837          0.  ORG2 0.99837          0.  ORG2 0.99837
ORG2 0.99837            0.   ORG2 0.99837         0.  ORG2 0.99837          0.  ORG2 0.99837          0.  ORG2 0.99837
ORG2 0.99837            0.   ORG2 0.99837         0.  ORG2 0.99837          0.
 STOCK BY UNIT AT ECHELON 2
DSU1                    1.   DSU2                 1.
 STOCK BY UNIT AT ECHELON 3
GSU1                   21.

ITEM6        S  C  L    17300          0     67.00  0.0700 PAA    1 100   0   0   0  93   0   0   0   1  30 100   0

WHOLESALE STOCK     1

AVAILBILITY AND STOCK BY UNIT AT ECHELON 1
ORG1 0.99917            0.   ORG1 0.99917         0.  ORG1 0.99917          0.  ORG1 0.99917          0.  ORG1 0.99917
ORG1 0.99917            0.   ORG1 0.99917         0.  ORG1 0.99917          0.  ORG1 0.99917          0.  ORG1 0.99917
ORG1 0.99917            0.   ORG1 0.99917         0.  ORG1 0.99917          0.  ORG1 0.99917          0.  ORG2 0.99917
ORG2 0.99917            0.   ORG2 0.99917         0.  ORG2 0.99917          0.  ORG2 0.99917          0.  ORG2 0.99917
ORG2 0.99917            0.   ORG2 0.99917         0.  ORG2 0.99917          0.  ORG2 0.99917          0.  ORG2 0.99917
ORG2 0.99917            0.   ORG2 0.99917         0.  ORG2 0.99917          0.
 STOCK BY UNIT AT ECHELON 2
DSU1                    0.   DSU2                 0.
 STOCK BY UNIT AT ECHELON 3
GSU1                    2.

   TARGET=                 0.010000

   THE NUMBER OF CURVE PARAMETERS TESTED=     1
     SIP SATISFIED TARGET
CURVE PARAMETER    AVAILABILITY     RETAIL COST
      0.01          0.930158        1019700.00

     6 ITEMS

                    * * * * *   SESAME SUMMARY REPORT  :            * * * * *

AREA = C  -   CURVE PARAMETER = $        0.01
                                  RETAIL                                                                STOCKAGE CODES
                       NSNS STR                   NSNS STR
      ECHELON   CLMNTS   ORDS   PAA        TPRS        ASP        $ASP                      F    S    A    U    D TOTAL
       ORG        28.     6      1      140000.00       0         0.0              LRUS      0    6    0
       DSD         2.    PA.     5      561800.00       0         0.0          NON LRUS           0    0    0    0
```

```
                                                                                                      PAGE 003
        GSU          1.        168.       6   317900.00            0          0.0         NON ESSEN         0
        TOTAL RETAIL $                        1019700.00                      0.0   THIS RUN HAD     6 LRUS IN THE INPUT DATA.
                                                                                        0 LRUS RECEIVED STOCKAGE GREATER THAN SIP.

       MTTR       MCTBF       MCTBF                       SUPPLY        OPERATIONAL
                 (INPUT)    (DERIVED)      MLDT       AVAILABILITY     AVAILABILITY
       2.50        75.         78.         3.131        0.959920         0.930158

                                            RESULTS BY UNIT FOR ASYMMETRIC STRUCTURE

AVAILABILITY AND $STOCK BY UNIT AT ECHELON 1
ORG1 0.93016         5000.  ORG1 0.93016        5000.  ORG1 0.93016        5000.  ORG1 0.93016        5000.  ORG1 0.93016        5000.
ORG1 0.93016         5000.  ORG1 0.93016        5000.  ORG1 0.93016        5000.  ORG1 0.93016        5000.  ORG1 0.93016        5000.
ORG1 0.93016         5000.  ORG1 0.93016        5000.  ORG1 0.93016        5000.  ORG1 0.93016        5000.  ORG2 0.93016        5000.
ORG2 0.93016         5000.  ORG2 0.93016        5000.  ORG2 0.93016        5000.  ORG2 0.93016        5000.  ORG2 0.93016        5000.
ORG2 0.93016         5000.  ORG2 0.93016        5000.  ORG2 0.93016        5000.  ORG2 0.93016        5000.  ORG2 0.93016        5000.
ORG2 0.93016         5000.  ORG2 0.93016        5000.  ORG2 0.93016        5000.  ORG2 0.93016        5000.  ORG2 0.93016        5000.

$STOCK BY UNIT AT ECHELON 2
DSU1             280900.  DSU2              280900.

$STOCK BY UNIT AT ECHELON 3
GSU1             317900.

       WHOLESALE BREAKOUT  REPAIR PIPELINE    CONSUMPTION
                                 0.0            72400.00 PAA
                                 0.0                0.0  ASP

       THESE RESULTS REFLECT THE COST OF PROVISIONING THE CLMNTS IN THE AREAS INDICATED ABOVE
                         PLUS THE COST OF $     72400. AT THE WHOLESALE LEVEL FOR 1.00 YEARS

        CORPAR =         0.01
    ASP BUDGET =         0.0
    PAA BUDGET =   1092100.00
    TOT BUDGET =   1092100.00
B: T=10.07/11.63 10:51:44
```

APPENDIX E
SESAME ACRONYM LISTING

ASM Asymmetric System Mode. Tells the model that a non-symmetric system is being entered as data.

BDENS Beginning Density. BDENS is the cumulative end item density at the beginning of the deployment year.

CONDEL CONDEL is the conditional delay time required for Major Subordinate Command to satisfy a demand for an out-of-stock item.

CURPAR CURPAR is the estimate, in dollar value of the cost attached to system downtime.

ERPSL Essential Repair Parts Stockage List. An ERPSL is a stockage list of demand supported and essential non-demand supported spares required to reach an operational availability objective.

ESS Essentiality Code. The ESS determines whether the part is essential to the system.

FIM Fault Isolation Module. FIM is defined as an item that requires removal and replacement to determine failure. If an item is defined as FIM it is required to have a minimum stockage of one spare.

LRU Line Replaceable Unit. An LRU is an essential item which is removed and replaced at field

level to restore the end item to operationally ready condition.

MCTBF Mean Calendar Time Between Failure. MCTBF is the expected uptime per cycle.

MLDT Mean Logistics Delay Time. MLDT is the expected delay until a operational spare becomes available.

MTD Maintenance Task Distribution. These are percentages of total system removals of the part that will be repaired at each level.

MTTR Mean Time To Repair. MTTR is the expected repair time when spares are available.

OPL Operating Level Days. OPL is the number of days of stockage that is used to sustain normal operations.

OST Order and Ship Times. This is the time required to move a spare from user and support units.

REPCYC Repair Cycle. REPCYC time is the number of days it takes to ship the part to the repair facility plus the number of days needed to repair the part. This value does not include the time necessary to return the part backed to the user.

REPR Replacement Rate. REPR is the percent of removed parts that is uneconomicably repairable.

RSC Retail Stockage Criterion. RSC is the number of demands per year that must be experienced by a unit before it is authorized to stock a spare.

RTD Replacement Task Distribution. RTD are the percentages of total system removals of the part

at each echelon.

SIP Standard Initial Provisioning. The SIP model is a mathematical model containing the procedures used in the provisioning procedure.

SRU Shop Replaceable Unit. An SRU is a component or assembly used in the repair of a component LRU when the LRU has been removed from the non-operational system.

TARGET TARGET is the search feature used in the SESAME model. When the TARGET value is set less than 1.0 it represents a target operational availability. For example, .95, represents a target of 95% operational availability. A value greater than 1 represents a dollar value. For example, 100 represents a search limit of one hundred dollars. Therefore, the model will search for the best operational availability using only one hundred dollars.

URR Unserviceable Return Rate. This is the amount of items that cannot be repaired at the depot level and must be replaced through wholesale stockage.

WHOFIL WHOFIL is the wholesale stock availability.

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6.	CPT. Carl F. Menyhert 30-53 88 Street Jackson Heights, NY 11369	3
7.	Mr. R.R. Shorey OSD (MR&L) Room 2B 323 The Pentagon Washington, D.C. 20301	1
8.	Mr. M.P. McGrath OSD (MR&L) Room 2B 323 The Pentagon Washington, D.C. 20301	1
9.	Dr. Larry Crow Army Materiel Systems Analysis Activity Aberdeen, Md. 21005	1
10.	Mr. Alan J. Kaplan U.S. Army Inventory Research Office Room 800 U.S. Custom House 2nd and Chestnut Streets Philadelphia, Pa. 19106	1
11.	Mr. Bernard Price U.S. Army ERADCOM ORDEL-PO-SA Ft. Monmouth, NJ 07703	1
12.	Dr. Charles Plumeri U.S. Army CECOM DRSEL-PL-E Ft. Monmouth, NJ 07703	1

13. Dr. Hans Ebenfelt 1
Systecon AB
Kungsgatan 8
S-111 43 Stockholm, Sweden

14. Department of the Army
Office of the Undersecretary
ATTN: SAUS-OR
Washington, D.C. 20310 1

15. Professor F. Russell Richards, Code 55RH 1
Department of Operations Research
Naval Postgraduate School
Monterey, Ca. 93943